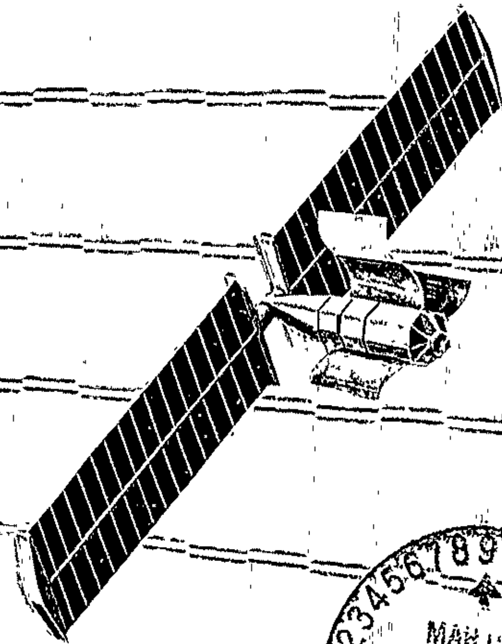
LMSC D614928 [redacted]
30 SEPT. 1978



NASA
George C. Marshall
Space Flight Center

25 kW POWER MODULE EVOLUTION STUDY

PART II PAYLOAD SUPPORT SYSTEM EVOLUTION FINAL REPORT

LOCKHEED MISSILES & SPACE COMPANY, INC.

12-6-78

FINAL REPORT
25 kW POWER MODULE EVOLUTION STUDY

PART II
PAYLOAD SUPPORT SYSTEM EVOLUTION
30 SEPTEMBER 1978
LMSC-D614928, [redacted]

For

National Aeronautics and Space Administration
George C. Marshall Space Flight Center

Contract No. NAS8-32928
DPD 555
DR No. MA-04

LOCKHEED MISSILES & SPACE CO., INC.
Sunnyvale, California

FOREWORD

This document presents the final report for Part II, Payload Support System Evolution, for the 25 kW Power Module Evolution Study. The report fulfills the Part II deliverable data requirement of NASA/Marshall Space Flight Center Contract No. NAS8-32928, as defined in DPD 555 for Data Requirement No. MA-04. Part I of the study, Payload Requirements and Growth Scenarios, has been documented in LMSC D-614921A dated 1 August 1978.

A three-volume report will be produced to document the results of Part III of the study, Conceptual Designs for Selected Evolutions. Part III will contain sections on Power Module Evolution; Mission Accommodations; and Trade Studies, Operations, and Programmatics. These three reports, plus the released report for Part I, comprise the final technical report for the study. An executive summary will also be produced at the conclusion of the study.

CONTENTS

BACKGROUND AND SYNOPSIS

The Part II study is the second of a three-part study. In outline form the total study scope is as follows:

Part I – Payload Requirements and Growth Scenarios (LMSC/TRW)

A 3-month analytical effort to develop payload application summaries and time-phased requirements that will drive the concepts for the 25 kW Power Module and the Supporting Systems definitions.

Part II – Definitions of Evolutionary Systems (LMSC/BENDIX/IBM)

A 6-month effort to establish the baseline capability of support elements; analyze evolutionary growth options for Power Module CPM and Support System elements; and develop and define alternative evolutions.

Part III – Conceptual Designs of Selected Evolutions (LMSC/BENDIX)

A 7-month conceptual design effort to further define two or more selected Power Module evolutionary growth/scenario systems.

This report summarizes the results of Part II of the 25 kW Power Module Evolution Study conducted for NASA/MSFC by LMSC. Part II of the study utilized the mission scenarios; integrated mission requirements developed in Part I; and defined several system evolutions that start with the 25 kW Power Module in 1983 and have the capability of accommodating the increasing mission requirements through 1990. The objective of Part II was to develop concepts; define development sequences; recommend and describe cost-effective modifications to the 25 kW Power Module and other candidate system elements; and develop the funding requirements for growth scenarios. The result of Part II is the Selection of three growth scenarios to be developed further in Part III, with emphasis on the near-term systems. Results of Part III will be reported separately.

The most significant results of this study are the clearly defined options to modularly grow the Power Module (PM) capabilities to 200 kW or more while it is on-orbit in LEO. The MSFC Power Module concept, utilizing common program developed hardware, is fully replicable. The decision to incorporate the modifications required to support the early free-flyer missions, or the option to incorporate the ability to grow on-orbit, will depend on the availability of early funding and mission definitions in the 1983 to 1986 time period.

Part II Study Content

The Part II effort is presented in this report according to the major task areas defined by the Study Plan:

- Support Element Capability
- Support Element Growth Capability
- Growth Scenarios by Discipline
- Growth Scenarios by Multidiscipline
- Power Module Growth Analysis
- Analysis and Recommendations for Part III Study

The following paragraphs outline the Part II study highlights and provide an overview of the report. This report is presented in accordance with NASA/MSFC format requirements as basic charts (right hand pages) and facing text pages which elaborate upon the chart data.

Support Element Capability Analysis and Growth

Data was obtained from NASA and industry on the baseline 25 kW Power Module and other flight and ground support elements of the Space Transportation System (See Appendix 1). These data included descriptions of the Orbiter, external tank, Teleoperator, Skylab, Spacelab, and associated support modules/pallets, KSC launch site, and tracking and data communications systems. Performance capabilities were extracted for each element and

modifications for interfacing and operating with Power Modules/support elements/payload-systems were identified. The Support Element Capability section summarizes STS elements capability.

In addition to reviewing documented descriptions of hardware, numerous contacts were made with industrial organizations that are currently developing hardware items for the STS elements. This permitted the direct transfer of hardware performance data and allowed the exchange of potential hardware new-development and growth ideas.

A specific visit by LMSC study personnel was made to NASA Kennedy Space Center, Florida, to review facilities, support equipment, and operation procedures that are being developed for the STS. This direct contact and familiarization with launch site ground operations helped to develop a realistic and acceptable approach to Power Module ground processing at the launch site. Handling, transport, and interfacing with the Orbiter were taken under consideration in hardware design and assembly concepts for the Power Module. Operations concepts and requirements will be developed in Part III of this study.

An important element of the capability assessment task was to examine the basic 25 kW Power Module to provide a firm basis for developing hardware growth concepts. The MSFC September 1977 25 kW Power Module baseline configuration was analyzed on a subsystem basis – structural, electrical power, thermal, attitude control, and communication and data handling – to assess replicability, performance, and growth potential. Tradeoff analyses in these subsystems were conducted to evaluate and define alternative subsystem configurations and to

verify selection of baseline designs. Results of these analyses were communicated to NASA personnel through telephone contact between related specialist personnel and through working meetings. The 25 kW Power Module baseline capability is summarized as part of the Support Element Capability section.

Analysis indicated that the growth of the STS elements such as the external tank, Skylab, Spacelab, and associated pallets, was primarily related to adapting the inherent capability of these elements to physically and functionally interface with the Power Module in a clustering concept. Element growth is summarized in the section on Support Element Growth Capability.

The major driver in the growth of the Power Module subsystems is the growth associated with the solar arrays. For the PM subsystems, growth is achieved through increased sizing and/or technology advances which promote increased performance efficiency. To achieve a commonality growth concept for the solar arrays, two basic solar array panels are defined. Used in multiple panel assemblies, output power can be increased from 25 kW through 250 kW. Power module subsystem growth is summarized in the section on Power Module Growth Analysis.

Requirement Synthesis

The Part I mission requirements were analyzed for composite power module and supporting element needs. It became readily apparent that the payload requirements could only be satisfied by a very ambitious program plan even when constrained to Material Processing, Public

Services, and Solar/Terrestrial missions. The minimum basic orbits were derived for composite mission scenarios, which are 28.5°, 57° (50° with Skylab), Polar, and Geo-synchronous orbits. To develop program growth scenario options sensitive to various funding constraints, composite requirements were developed for ambitious, nominal, and minimum scenarios. There was no attempt to prioritize the payloads or define specific payload groupings for each evolutionary stage. Rather, the composite requirements were scaled and the supporting elements were configured so that a system capability analysis could be made, based on the needs represented in each of the scenarios.

These requirement charts were continually reviewed and revised after coordination with the MSFC/COR. These three levels (ambitious, nominal, and minimum) of scenarios and the supporting Power Module and element capability summary analysis are the basis for Multidiscipline Growth Scenarios..

System Evolutionary Growth Scenarios

The study plan was structured to develop evolutionary growth scenarios for each selected mission discipline. Scenarios were developed for Solar Terrestrial, Materials Processing, Public Services, and Energy Technology Demonstrations as identified in Part I. It became obvious that each of these missions required an ambitious program with many dedicated Power Modules. It was established that this task should be modified to establish various levels of requirements with matching capabilities for incremental growth of composite

multimission scenarios that would establish the various levels and distribution of funding considered to be within a practical range.

Requirements were developed and growth scenarios conceptualized for ambitious, nominal, and minimum levels from 1983 through 1990, for each of the basic orbits (28.5°, 50° - 57°, Polar, and GEO), both with and without Skylab in the scenario. The major advantage of Skylab is the early habitability capability and/or the option to conduct manned orbiting mode missions at minimal program costs.

The ability to readily increase the Power Module incrementally on-orbit was a major accomplishment and had a significant influence on the evolutionary stage configurations. The ability to retain the high value solar arrays, on-orbit, and combine them with new solar array kits with relatively low cost structural boom assembly kits, permits growth to 200 + kW with feasible system configurations. Each evolutionary growth stage of the Power Module is feasible within the weight and volume capability of the Orbiter. This permits balanced cargo manifests between modular growth of the Power Module, payloads, and other supporting elements.

Power Module Growth Options

The matrix of mission scenarios was utilized in formulating a projection of growth requirements for each of the subsystems. These also integrated into composite requirements for

growth of the Power Module in a logical time-phased sequence in each of the several orbits required in the mixed-discipline scenarios. It became evident that modular growth on-orbit, without return to earth, is an attractive option because growth appears to be required before the life of the Power Module(s) on-orbit has expired. Accordingly, each subsystem evolutionary growth projection has been predicted on ability to implement growth on-orbit by means of modular changes implemented by EVA disassembly/assembly operations.

On-orbit modular growth imposed constraints on the structures subsystem. Several optional configurations were conceived for implementing each growth step from 25 kW to 250 kW Power Modules, using old hardware with unexpired life and at the same time enabling incorporation of technology improvements. With the larger Power Modules, incorporation of new technology in each of the subsystems becomes increasingly important.

The electrical power subsystem grows to 250 kW, essentially with two sizes of solar array blankets, and several step improvements in power-regulation and conversion efficiencies, batteries, and solar cell efficiencies. Extension of the solar array packaging and deployment concepts suggested for the 25 kW Power Module, allows the ability to effect modular growth on-orbit to as much as 250 kW.

For thermal control, the heat rejection system provides for 4 kW to 11 kW service to the payloads in the 25 kW configuration, then doubles in capability for the 50 kW Power Modules. At 100 kW and above, heat rejection is assumed to be required only for the batteries, since the power utilization by payloads occurs at increasing distances from the heat rejection systems on the Power Modules.

As with thermal control, the attitude control system initially requires major growth in going from 25 kW to 50 kW. At higher levels, distributed sensors and actuators, and possibly a dual integrated attitude control system, are likely to be required.

For Control and Data Handling (C&DH) both early free-flyer needs and potential growth requirements are addressed. This subsystem analysis identified the need for incorporating higher data rate capability with a high-gain antenna to meet early free-flyer mission requirements.

INTRODUCTION
PART II

- The primary objective of the study is to define how the 25 kW Power Module can be evolved by the addition of system elements in evolutionary steps to meet future mission requirements. The mission requirements are described and summarized in Part I.

- The objective of Part II is to conceptualize logical evolutionary paths, by discrete growth stages, that will have the capability of accommodating the increasing mission requirements through the early 1990s within reasonable resources. The results of Part II are to recommend two or more evolutionary scenarios for a more detailed analysis in Part III.

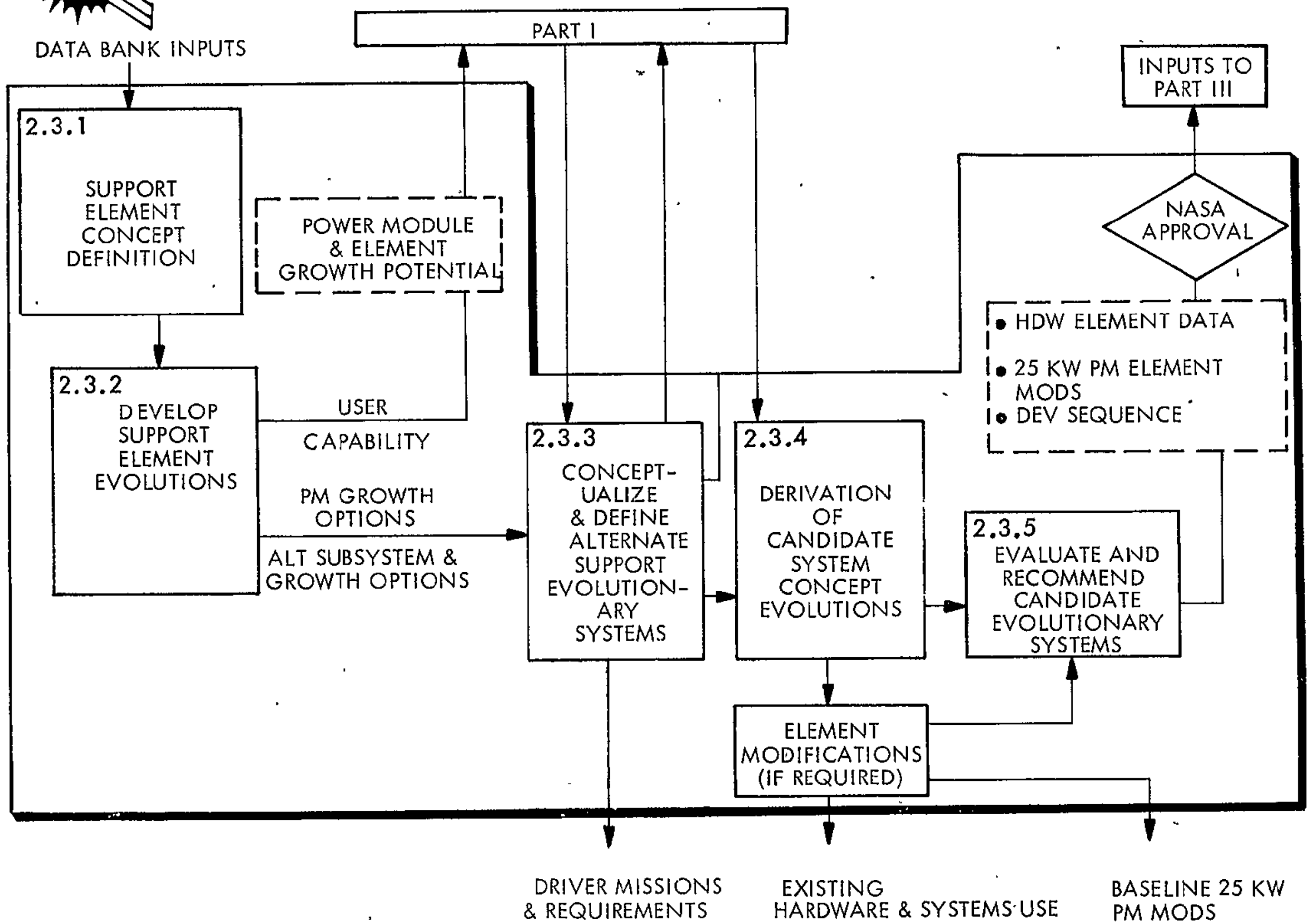
PART II OBJECTIVE

- TRANSLATE THE PART I MISSION REQUIREMENTS INTO SYSTEM DESIGN REQUIREMENTS.
- DEFINE AND RECOMMEND TWO OR MORE EVOLUTIONARY PATHS FOR MORE DETAILED CONSIDERATION IN PART III.

- Early Part II Study activities work in parallel with and support Part I to develop the Payload Growth Scenarios. This early study interaction is illustrated and defines Mission Requirements, and identifies the requirements that drive the growth scenarios, the Power Module, and other support element hardware. Comparative analysis is made between support element capabilities and payload requirements.

- The results of the Part II Study provide the recommendations of two or more concepualized scenarios to be developed further in Part III. System level trade studies and conceptual designs are developed using subsystem parametric performance data. These trade studies are performed against the MSFC baseline design to develop recommendations for modifications that may be required to both meet the early mission requirements and for the ability to grow to meet the evolutionary requirements.

PART II DEFINITION OF EVOLUTIONARY SYSTEMS



- This chart illustrates each major task of Part II and the key subtask elements of the study. The major study emphasis is placed on Task 2.3.4 Growth Scenarios by Multidiscipline, with emphasis on the near-term and the Power Module interfaces. This includes the preliminary design activities for the optional Power Module for both the first and subsequent modules that require growth options.

- The programmatics are developed for each growth scenario to support the rationale for selecting those scenarios recommended for additional study in Part III.

PART II TASK CONTENTS

2.3.1 SUPPORT ELEMENT CAPABILITY

- POWER MODULE
- SPACELAB
- EXTERNAL TANK
- SKYLAB
- INTERFACE MODULE
- TELEOPERATOR

2.3.2 SUPPORT ELEMENT GROWTH CAPABILITY

- POTENTIAL GROWTH
  1983 – 1990 +

2.3.3 GROWTH SCENARIOS BY DISCIPLINE

- MATERIAL PROCESSING
- STO
- PUBLIC SERVICES
- ENERGY

2.3.4 GROWTH SCENARIOS BY MULTIDISCIPLINE

- COMPOSITE REQUIREMENTS
- SYSTEM CAPABILITY ANALYSIS
- CONFIGURATION CONCEPTS
  - 28.5° ORBIT
  - 50° ORBIT
  - 57° ORBIT
  - POLAR
  - GEO

POWER MODULE GROWTH ANALYSIS

- EVOLUTION 1983 – 1990 +
  - SUBSYSTEM
  - SYSTEM OPTIONS

2.3.5 EVALUATION AND RECOMMENDATIONS FOR PART III STUDY

- GROWTH SCENARIOS
- PM GROWTH
- PROGRAMMATICS

BASELINE MISSION SUPPORT CAPABILITIES

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- The chart illustrates planned Space Transportation System element capabilities as they relate to Power Module System evaluation. The basic mission is identified for each element.

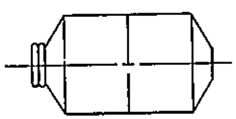
- Readily derivitive capabilities which intermesh with Power Module applications are described.

- In the interest of completeness, an abbreviated description of 25kW Power Module capabilities is also included.

ELEMENT CAPABILITIES

SPACELAB

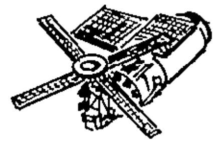
- 7 kW (ORBITER)
- PALLET PAYLOADS
- MATE WITH FREE-FLYING POWER MODULE FOR POWER, THERMAL, C&DM, AND STABILITY



IOC: 1980
CREW: 2 TO 5
MISSION: 7 TO 15 DAYS

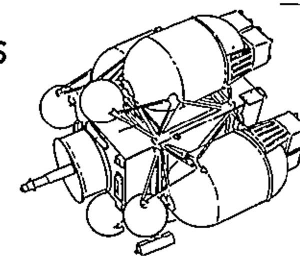
SKYLAB REUSE

IOC: 1984
CREW: 3 TO 7
SORTIE: 90 DAYS



- 5 TO 10 kW POWER
- LARGE WORK AREA WITH LIFE SUPPORT SUBSTATIONS
- NEEDS AUDIO/VIDEO LINK FOR TDRSS
- APOLLO DOCKING (ONLY)

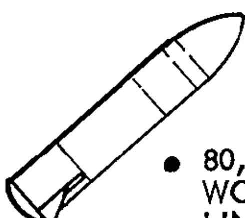
TELEOPERATOR



- UNMANNED ORBIT SPACE TUG WITH SELF-CONTAINED SUBSYSTEMS
- PROGRAMMABLE OR MANUAL (REMOTE SHUTTLE) CONTROL

IOC: 1979
MISSION: SKYLAB REBOOST/ DEORBIT

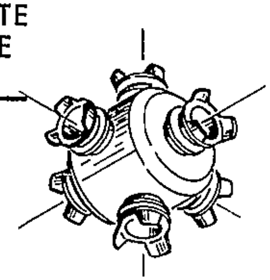
EXTERNAL TANK



- 80,000 FT^3 ORBIT WORK STATION
- LINK WITH OTHER SUPPORT ELEMENTS VIA INTERFACE MODULE

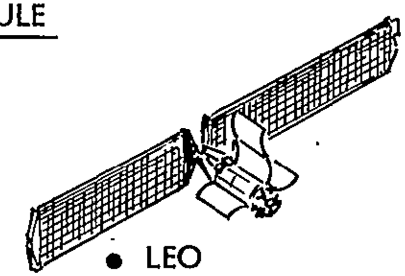
IOC: 1979
ORBITER PROP. DROP TANK

CANDIDATE INTERFACE MODULE



- DOCKING COLLARS (6) PORTS
- INTERFACE FOR SUPPORT ELEMENTS

25 kW POWER MODULE



- LEO
- GEO DERIVATIVE
- 5 YR ORBIT LIFE

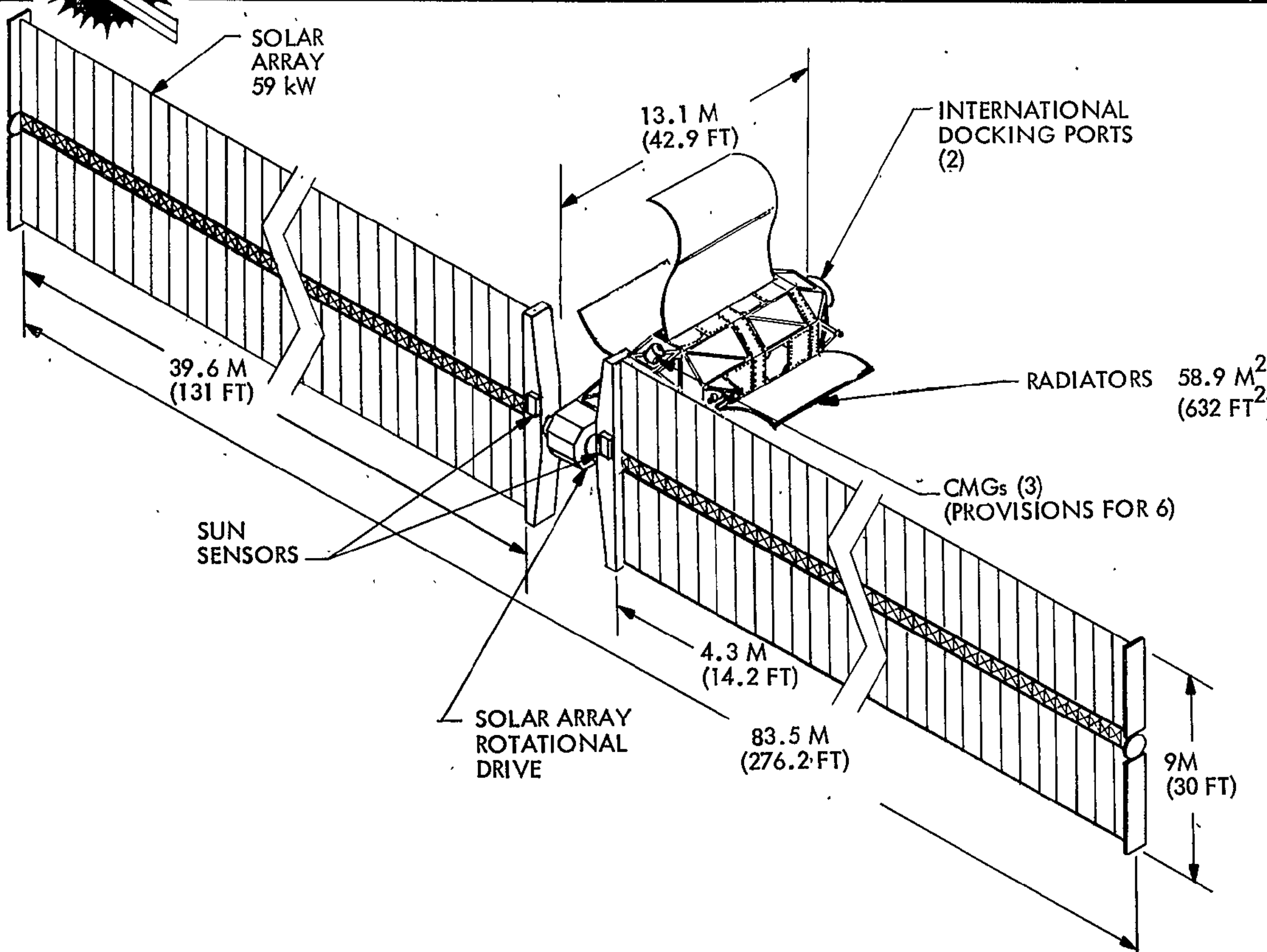
10C: 1983

- The initial 25 kW Power Module (PM) baseline configuration emphasizes use of existing hardware. For its basic structure, the design uses two octagonal rack structures from the ATM Program attached in tandem arrangement. A truss support structure is mounted to the forward rack. The solar array drive assembly and solar array wings are attached to this forward support structure. A docking adapter with multiple ports is attached at the rear of the aft structure. Curved thermal radiator panels from orbiter are attached in a hinged, foldout/retract arrangement to the ATM racks. Control moment gyros from the Skylab Program are used for attitude control. (Ref: NASA/MSFC "25kW Power Module Preliminary Definition," dated Sept. 1977.)

- The solar array (S/A) panels are extendable/retractable and form an extended wing array 9 meters (30 ft) wide by 83.5 meters (271 ft) long. The S/A has a single degree of rotation about the longitudinal axis for solar pointing and provides 59 kW peak output with 25 kW average power to the user.

- Control moment gyros are mounted in the forward support structure and the major avionic equipment and batteries are located in the ATM racks.

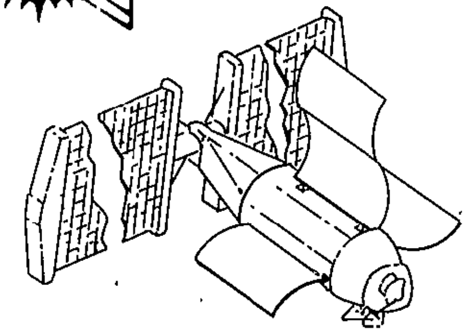
25kW PM MSFC BASELINE CONFIGURATION



- The 25 kW PM provides longer life to the Oribiter for sortie operations and also provides capability to operate as a long-duration free-flyer in direct support to payload users. Basic capabilities to users include average electrical power output of 25 kW, thermal heat rejection up to a 14 kW maximum, and attitude stabilization and control through control moment gyros within a pointing accuracy of ±0.5 degrees. By design, no contaminating by-products are generated in any PM operations.

- The PM provides operational capability for low-earth orbits, and affords a potential for derivative support capabilities in geosynchronous equatorial orbits, with an expected 5 year orbit operational life. Design provisions are included to accommodate on-orbit maintenance of PM systems via EVA. The PM is capable of operating in three operational support modes — sortie mode, free-flyer mode, and orbital-storage mode.

25kW POWER MODULE CAPABILITY



MISSION OPERATIONS

ORBIT	–	235 NM LEO - 28.5 TO 57° AND POLAR INCL
	–	GEOSYNCHRONOUS EQUATORIAL ORBIT
ORBIT DECAY	–	REBOOST BY ORBITER
ORBIT LIFE	–	5 YEARS ORBIT OPERATIONAL – 50% DUTY CYCLE
ORBIT MAINTENANCE	–	VIA EVA USING RMS FOR ALL SYSTEMS – ALL SYSTEMS – MODULAR REPLACEMENT

SYSTEM CHARACTERISTICS / OPERATIONAL MODE	SORTIE PM/ORB/PAYLOAD	SORTIE PM/PAYLOAD	FREE-FLYER PM/PAYLOAD	ORBIT STORAGE
POWER (AVERAGE ON-ORBIT)	14 kW TO ORBITER 11 kW TO PAYLOAD	25 kW TO PAYLOAD	25 kW TO PAYLOAD	ARRAYS FOLDED 1.9 kW FOR PM HOUSEKEEPING
THERMAL HEAT REJECTION	P/L HEAT → ORB → PM 11 kW TO 5 kW	P/L HEAT → ORB / PM 12 kW TO 6 kW	P/L HEAT → PM 14 kW TO 7 kW	PM HOUSEKEEPING ONLY
STABILIZATION AND CONTROL	CMG	CMG	CMG	CMG
POINTING ACCURACY	0.5°	0.5°	0.5° WITHIN ±10° OF SUN	0.5° WITHIN ±10° OF SUN
POINTING STABILITY	(1) TBD	(1) TBD	(1) TBD	(1) TBD
COMMUNICATIONS	ORBITER HARD LINE RF THROUGH TDRSS	ORBITER HARDLINE RF THROUGH TDRSS	RF TO ORBITER RF THROUGH TDRSS	RF THROUGH TDRSS
DATA HANDLING	TLM - 4 KBPS COMPUTER - 16,027 WORDS (16 BITS)	TLM - 4 KBPS COMPUTER - 16,027 WORDS (16 BITS)	TLM - 4 KBPS COMPUTER - 16,027 WORDS (16 BITS)	TLM - 4 KBPS COMPUTER - 16,027 WORDS (16 BITS)
DOCKING	ORBITER	ORBITER/PAYLOAD (2)	MULTIPLE PAYLOADS (2)	UNDOCKED
MISSION DURATION	ORBITER LIMITATION	ORBITER LIMITATION	INDEFINITE	INDEFINITE

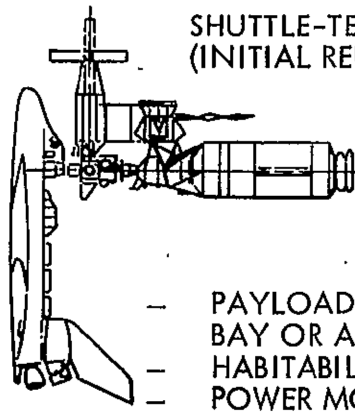
(1) TBD - THIS IS A FUNCTION OF BANDWIDTH DETERMINATION (2) INCLUDES SKYLAB, SPACELAB PALLETS, OR MANNED MODULES

- Recent Skylab Reuse studies and data currently being received from Skylab telemetry indicate that Skylab can immediately provide a large habitable volume with supporting subsystems that can support a crew of three. There is a requirement to replace the audio and video link that was formerly provided through the CSM and establish a compatibility with TDRSS. The electrical power generated on-board will be a function of the β angle. Finally, the docking system is compatible only with the Apollo system.

- Other data on the chart are self-explanatory; quantities are derived from information presented in the McDonnell Douglas and Martin Marietta studies.*

*MDC Report No. G7378, "Skylab Reuse Study Midterm Review," dated 4/78
Martin Marietta Program Review, "Skylab Reuse Study," dated 4/78
MDC Report No. G7538, "Skylab Reuse Study Final Briefing," dated 8/17/78.

SKYLAB REUSE BASELINE CAPABILITY



SHUTTLE-TENDED
(INITIAL REUSE OPERATIONS)

- PAYLOADS OPERATED IN THE CARGO BAY OR ATTACHED TO CLUSTER
- HABITABILITY COMPLETE (3 CREW)
- POWER MODULE ADDED

MISSION

- IOC 1984 (WITH PM)
- CREW OF THREE TO SEVEN
- SORTIE MISSION DURATION OF 90 DAYS

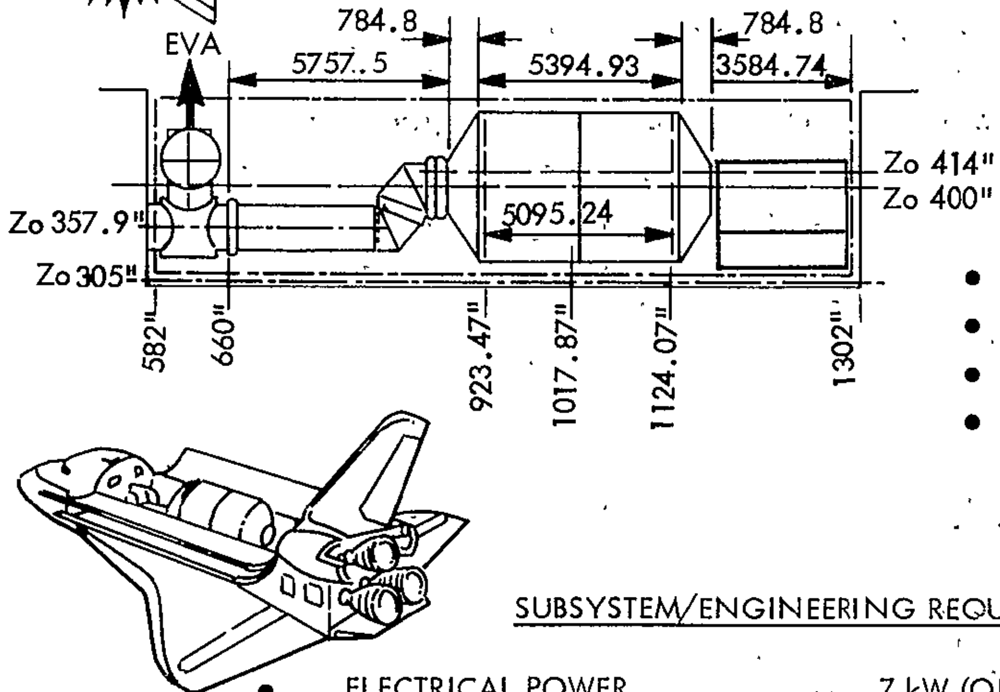
SUBSYSTEM/ENGINEERING REQUIREMENTS

• ELECTRICAL POWER	– 5 TO 10 kW
• ATTITUDE CONTROL	– POINTING ACCURACY 1 TO 3 DEGREES – STABILITY ±0.5 DEGREE, STABILITY RATE ±0.05 DEGREE/SECOND
• THERMAL CONTROL	– OPERATIONALLY SELF-SUFFICIENT
• COMMUNICATIONS AND DATA HANDLING	– COMMAND AND TELEMETRY SYSTEM OPERATING FREQUENCIES VIOLATE FCC REGULATIONS – AUDIO AND VIDEO REQUIRE COMMAND MODULE SUBSTITUTE OR TDRSS KIT
• DOCKING	– APOLLO SYSTEM

- Baseline capabilities of the "long" spacelab module are summarized in the chart. Not shown is the pallet that provides a framework onto which space experiments (or cargo) can be mounted for transport to orbit via the space shuttle and the "short" module. The pallet (or the spacelab described in the chart), with space experiments attached, ultimately is expected to be mated to a free-flying power module which thereafter supplies the necessary power, heat rejection, attitude stabilization, and command and data handling essential to satellite mission operations.

- Initial spacelab operations, of either the module or the pallet configurations, are planned as sortie missions accomplished from within the Orbiter payload bay as illustrated in the chart. Quantities shown are derived from information contained in ERNO report PRV-6 No. 2/78, "Study of the Use of Spacelab Derived Elements Within Different Possible Steps Towards a Space Platform," dated 1/78.

SPACELAB BASELINE CAPABILITY



MISSION

- IOC 1980
- CREW OF 2-5
- MISSION DURATION OF 7-15 DAYS
- PALLETS TO DELIVER CARGO/ EXPERIMENTS TO ORBIT

SUBSYSTEM/ENGINEERING REQUIREMENTS

- ELECTRICAL POWER – 7 kW (ORBITER PROVIDED)
- ATTITUDE CONTROL – ORBITER PROVIDED CAPABILITY
- THERMAL CONTROL – 0 TO 8.5 kW (ORBITER PROVIDED)
- SYSTEM RELIABILITY – 0.95 FOR 7-DAY MISSION
  – 0.90 FOR 15-DAY MISSION

- The Teleoperator retrieval system in its configuration for the Skylab Boost Mission, is a vehicle approximately 10.5 ft dia x 11 ft tall, capable of accomplishing a variety of useful tasks on-orbit. It is controlled either through preprogrammed instructions from its Communication and Data Management Computer, or through manual control by a shuttle crew member using support equipment in the Orbiter. As indicated in the chart, its initial application is in connection with Skylab retrieval.

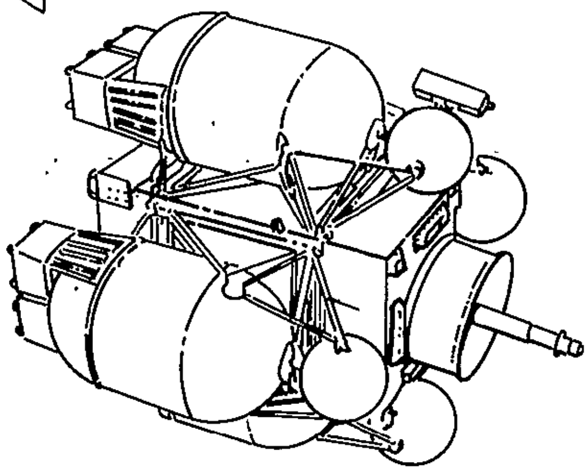
- The basic TRS vehicle contains six subsystems:

  - Structures and Mechanisms
  - Thermal Control
  - Guidance, Navigation, and Control
  - Propulsion
  - Communication and Data Management (two TV cameras)
  - Electrical Power and Distribution

- System characteristics and performance data* of interest in power module applications are summarized in the chart.

* Ref: MMC Paper, "Teleoperator Retrieval System," by R. J. Malloy, J. R. Tewell, and R.A. Spencer. NASA Fact Sheet Release No. 78-49, "Teleoperator Retrieval System," dated 3/31/78.

TELEOPERATOR BASELINE CAPABILITY



PERFORMANCE DATA

GROSS WEIGHT (WET)	9,900 LBS
BASIC CORE (WET)	2,300 LBS
4 BASIC PROPULSION KITS (WET)	7,600 LBS
DRY WEIGHT	3,440 LBS
BASIC CORE	1,870 LBS
4 PROPULSION KITS	1,570 LBS
PROPELLANT: CORE	25,000 LB. SEC.
(N_2H_4) KITS (4)	1,350,000 LB. SEC
PROPULSION KIT THRUST (EACH)	300 LBS
RF LINK RANGE	760 N. MILES

PLANNED MISSIONS

- IOC DATE 1979
- SKYLAB REBOOST OR DE-ORBIT

SYSTEM CHARACTERISTICS

- 24-NOZZLE GUIDANCE AND ATTITUDE CONTROL SYSTEM, 6 DEGREES OF FREEDOM
- STRAP-ON PROPULSION KITS (4)
- DOCKING PROBE SYSTEM
- COMMUNICATION AND DATA MANAGEMENT
- MANUAL CONTROL CAPABILITY
- RMS GRAPPLING FIXTURE; ASE FITTING
- TV CAMERAS (2); ILLUMINATION SYSTEM
- THERMAL CONTROL SUBSYSTEM

- Several alternate docking concepts are described in the power module preliminary definition document issued by MSFC*. The chart illustrates an interface module that can serve firstly as a pressurized interconnecting docking module for IVA between habitable elements, and secondly, as a docking capability to berth either pressurized or non-pressurized elements together in a variety of configurations.

- As illustrated and described on the chart, this interface module will have many applications in extending either manned or unmanned mission capabilities. If near-term missions will not require internal pressurization with shirt-sleeve IVA operations, a lighter and less complex unpressurized prototype may initially suffice. However, if the power module is equipped with two or three docking rings, the need for an unpressurized interface module disappears. The baseline power module would function as an interface module inter-connecting the orbiter and one (or two) additional space system elements, assuming only EVA (or unmanned) access/operation of these elements was performed.

*NASA/MSFC "25 kW Power Module Preliminary Definition," dated 9/77

PAYLOAD DOCKING MODULE GROWTH POTENTIAL

- ROTATABLE INTERFACE ADAPTER

  ALLOWS CLOCKING OF MATING ELEMENTS AND FACILITATES DOCKING AND DEMATING.

- EMERGENCY ECLS PACK

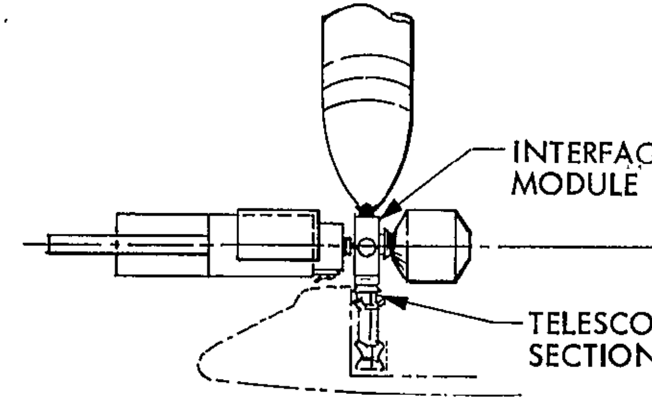
  PROVIDES AN ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS) MODULE ENABLING USE OF INTERFACE MODULE AS SHORT-TERM LIFE-RAFT.

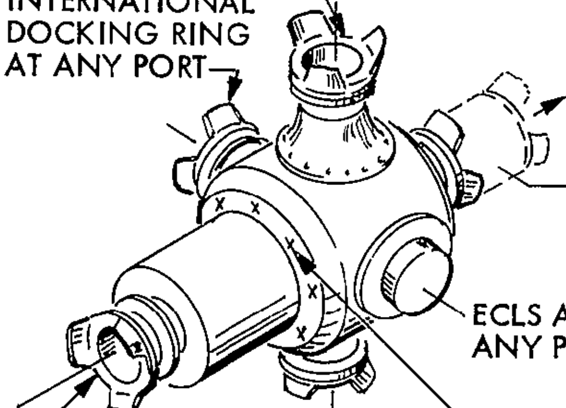
- AIRLOCK CHAMBER

  PROVIDES AIRLOCK FOR EVA OR IVA OPERATIONS WITH ANY ELEMENT COM COMBINATION.

- CYLINDRICAL ADD-ON SEGMENTS

  PROVIDES ADDITIONAL PRESSURIZED VOLUME AND INCREASED CLEARANCE BETWEEN MATING ELEMENTS.





POWER MODULE SUBSYSTEM GROWTH ANALYSIS

- GROWTH OPTIONS
- CANDIDATE POWER MODULES
- GROWTH KITS
- GROWTH POWER MODULE WEIGHTS

- Subsystem analyses were performed to support the definition of the Power Module growth evolution. Concepts for subsystems growth were developed to achieve PM growth from the 25 kW Power Module Design, described in the MSFC September, 1977 report, to 250 kW. This maximum size power module growth is based on the needs in the early 1990's. The fundamental requirements and objectives of these analyses are shown in the chart.

- Analysis included tradeoffs of implementing techniques, hardware elements, and technology influence to develop design growth concepts. Subsystems growth evolution is forecast by balancing increased sizing and advanced technology to achieve the performance capabilities in supporting Power Module mission growth scenarios. Subsystems weight growths are included (see later charts) to permit cost estimates.

SUBSYSTEM REQUIREMENTS AND OBJECTIVES

REQUIREMENTS

- CONCEPTS FOR GROWTH FROM 25 TO 250 kW
- BASE OF MATURE HARDWARE
- DEFINE TECHNOLOGY EVOLUTION
- EVALUATE MSFC 25 kW BASELINE
- RECOMMEND SUBSYSTEM DEVELOPMENT DATA
- DERIVE PARAMETETRIC SUBSYSTEM DATA

OBJECTIVES

- SATISFY ABOVE REQUIREMENTS BY
    - TRADEOFF ANALYSIS
    - REVIEW OF TECHNOLOGY STATUS
- EXPLOIT PLANNED TECHNOLOGY ADVANCES
- SHUTTLE COMPATIBILITY
- MINIMIZE TOTAL COST

STRUCTURES SUBSYSTEM ANALYSES

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- The structural design of the Power Module (PM) is strongly governed by Orbiter payload bay dimensions and hardpoint capabilities, ascent and landing accelerations, and other associated environments. Conventional handling and transport load criteria for spacecraft design is also utilized. These criteria are well documented and are not repeated in this report. (Refer to NASA/JSC ICD No. 2-19001, "Shuttle Orbiter/Cargo Standard Interfaces," Change 1 dated 4/28/78).

- Structural criteria which are unique for the PM are summarized on this chart. The first three items on the chart address the basic structual design conditions for large satellite vehicles in their zero-g orbital configuration.

- Because of the inherent flexibility of both the large solar arrays and the multiple structural configurations planned, it is anticipated that the attitude control system(s) will be designed with acceleration feedback loops and will be programmed to avoid dynamic load amplifying commands.

- Other Space Transportation System studies have arrived at essentially identical conclusions in regard to the relationship between structural and attitude control design criteria. (Refer to Grumman Report No. NSS-LS-RP012, "Systems Definition Study for Shuttle Demonstration Flights of Large Space Structures," dated April 18, 1978, pages 115, 128, and 139.

- Grapple points for the RMS are designed for maximum load capabilities of the RMS. These loads are small and have negligible affect on design of the PM other than in the local area at the grapple points. (Refer to SPAR Aerospace Products Ltd report, "A Review of SPAR's Remote Manipulator System Activities and Capabilities," dated 1978).

DOCKING & ORBITAL MANEUVER STRUCTURAL CRITERIA

1. "SOFT" DOCKING MANEUVERS:
   - STS ELEMENTS PLACED IN BERTHING/DOCKING POSITIONS WITH RMS
   - NEGLIGIBLE IMPACT OR JOINING LOADS EXCEPT IN LATCH MECHANISMS
2. ORBIT ADJUST MANEUVERS
   - IN GENERAL, HIGHLY FLEXIBLE STRUCTURES MUST BE IN "STOWED" POSITION
3. ATTITUDE CONTROL TRANSLATIONAL/ROTATIONAL ACCELERATIONS
   - PRODUCE DESIGN LOADS FOR DOCKING-JOINTS & FLEXIBLE/DEPLOYABLE STRUCTURES
   - QUASI-STATIC LIMIT LOADS ARE MINIMUM OF TWICE RIGID-BODY ACCELERATION LOADS
4. ATTITUDE CONTROL SYSTEMS DESIGN CONSTRAINT
   - DESIGNED TO AVOID DYNAMIC-COUPLING LOAD AMPLIFICATION
   - LARGE FLEXIBLE-STRUCTURES/ELEMENT-COMBINATIONS CANNOT BE STIFFNESS-DESIGNED TO AVOID THIS CONSTRAINT
5. COUPLED MULTIPLE CONTROL SYSTEMS
   - LARGE FLEXIBLE STRUCTURAL CONFIGURATIONS MAY REQUIRE MULTIPLE SEPARATELY-LOCATED ATTITUDE CONTROL SYSTEMS
   - INTEGRATED STRUCTURAL-RESPONSE FEEDBACK LOOPS MAY BE REQUIRED TO AVOID EXCESSIVE STRUCTURAL-LOAD DYNAMIC AMPLIFICATION

- With growth versions of the Power Module, both the volume and the weight limitations inherent in the Orbiter payload bay become more binding. Innovative packaging concepts for 50 kW, 100 kW, and even 250 kW configurations provide a potential capability of carrying these larger PMs in the payload bay. However, weight limitations become a critical factor.

- The initial 25 kW PM configurations utilize conservative structural design safety factors to minimize structural qualification testing and thereby reduce development program costs. As the PMs grow in size, the weight limitations are likely to necessitate reduction of this conservation, with attendant increased structural testing and associated costs. The typical relationship between safety factor and qual test criteria is presented in the chart.

- While the Option I design/test criteria combination has been utilized in the initial design studies, a preliminary estimate using the Option III criteria indicates a potential for approximately a 25 percent structural weight reduction. Such a weight reduction is coupled with an attendant increase in qual test scope, complexity, and cost. This may be cost-effective as a result of reductions in numbers of Orbiter launches and/or EVA assembly requirements, especially for the larger Power Module "growth" configurations. (Refer to the Power Module system weight chart under "Power Module Growth.")

STRUCTURAL SAFETY FACTORS VS QUAL TEST REQUIREMENTS

OPTION	FACTORS OF SAFETY		QUAL TEST REQUIREMENT
	YIELD	ULTIMATE	
I[1]	2.0	3.0	NONE[2]
II	1.4	2.0	TEST FLIGHT ARTICLE TO 1.1 TIMES LIMIT LOADS
III	1.0	1.4	TEST STRUCTURAL TEST ARTICLE TO DESIGN ULTIMATE, OR HIGHER

NOTES:

(1) OPTION I IS PRESENTLY SHOWN IN MSFC-SPEC-582A, POWER MODULE SYSTEM DESIGN REQUIREMENTS DOCUMENT.

(2) EXCEPT POSSIBLY FOR CRITICAL COMPONENT AND/OR SUBASSEMBLY TEST(S).

- Three alternative design concepts for the main body structure (equipment rack) are shown in the chart. Comparative evaluation of these concepts indicates important advantages with Concepts II and III, as apposed to concept I (the ATM baseline configuration).

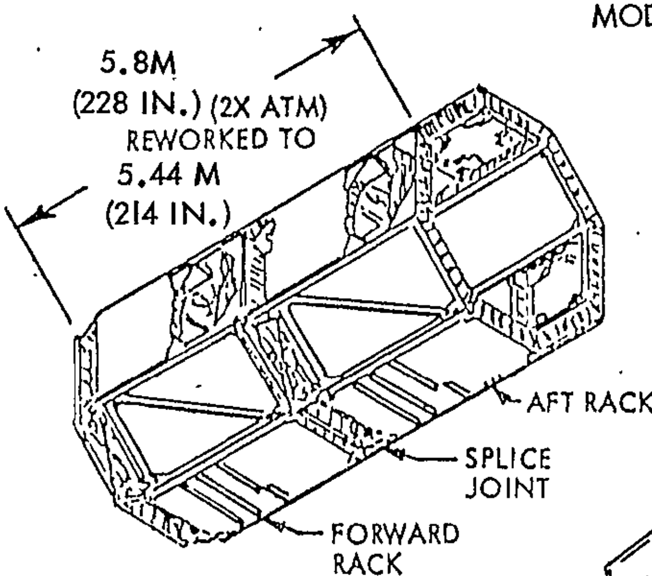
- Design concepts II and III both contribute to a shorter overall length of the Power Module than Concept I. This avoids structural interference problems. Other advantages/ disadvantages are summarized on the next chart.

- Concept III (SSM equipment racks) offers economic advantages resulting from its commonality with the Space Telescope project. More detailed trade studies are required to determine which of the two rack designs, concept II (new design), or Concept III (SSM rack), is the better candidate.

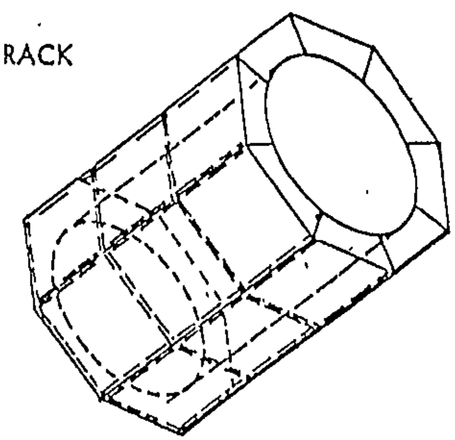
References: LMSC EM. B-1.1.2-101 "SSM vs Baseline Power Module with Alternate Solar Array and Radiator Configurations" dated 6/1/78. LMSC EM C-1.2.1-102, "Structural Assembly Trade Studies," dated 6-15-78. LMSC Drawing 6164-038, "Baseline Configuration, 25 kW Power Module."

MAIN BODY STRUCTURE-
ALTERNATIVE CONCEPTS

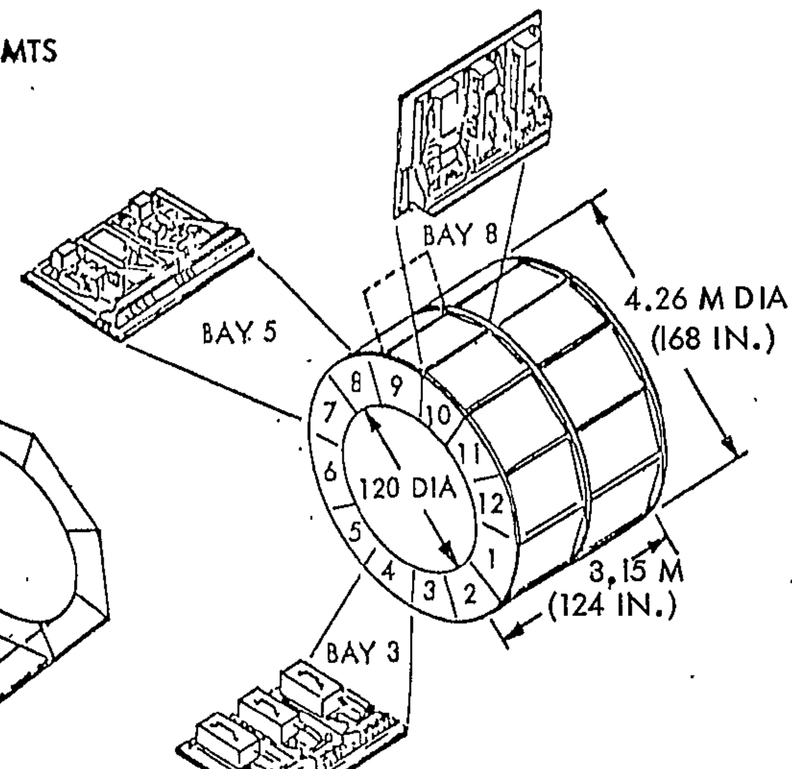
CONCEPT I
2 ATM EQUIPMENT RACKS
SPLICED TOGETHER



CONCEPT II
NEW DESIGN
TAILORED TO POWER
MODULE/ORBITER REQMTS



CONCEPT III
2X SSM EQUIPMENT RACKS
SPLICED TOGETHER



- The advantages and disadvantages of each of the three design concepts for the Power Module are itemized here.

- The significant disadvantage of Concept I (ATM Rack) overriding the advantage of its existing-hardware availability, is the rework necessary to: (1) avoid the interference problems that it incurs forward of station X. 660 in the Orbiter payload bay, and (2) satisfy space shuttle interface/attachment requirements.

- Concepts II and III possess the common advantage of compliance (by design) with space shuttle interface requirements. The other advantages and disadvantages between these two concepts need greater depth of study to determine their relative importance.

MAIN BODY STRUCTURE COMPARATIVE EVALUATION

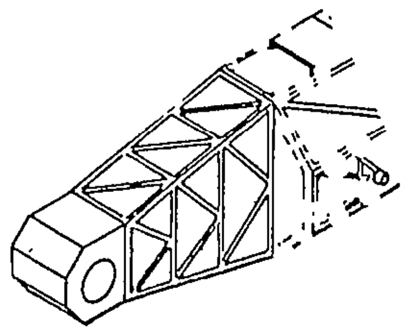
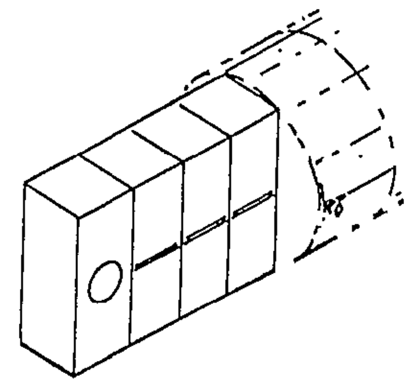
WEIGHT	CONCEPT I ATM EQUIP. RACK 3906 LB	CONCEPT II NEW DESIGN N/A	CONCEPT III SSM EQUIP. RACK 2700 LB
ADVANTAGES	• HARDWARE IS EXISTING AND AVAILABLE • EASY INSTALLATION OF EQUIPMENT – LESS COLD PLATE INTERCONNECTS • COULD BE PRESSURIZED FOR IVA • EASY INTERNAL ACCESS TO SMALL EQUIPMENT ITEMS BY ASTRONAUT – NO TETHER REQUIRED	• DESIGN TAILORED TO POWER MODULE REQUIREMENTS AND SPACE SHUTTLE INTERFACE • DESIGN TAILORED FOR INSTALLATION OF EQUIPMENT INTERNALLY AND EXTERNALLY • DESIGN CONTRIBUTES TO SHORTER OVERALL LENGTH OF POWER MODULE • COST EFFECTIVE DESIGN – ALLOWS OPTIONAL SELECTION OF STRUCTURAL FACTORS OF SAFETY VERSUS SCOPE OF STRUCTURAL TEST PROGRAM • TOOLING WILL EXIST – EASY TO REPEAT PRODUCTION	• COMMONALITY WITH SPACE TELESCOPE PROJECT MEANS ECONOMY • TOOLING AND HANDLING EQUIPMENT WILL EXIST • WILL BE A TESTED, QUALIFIED UNIT • CONTRIBUTES TO SHORTER OVERALL LENGTH OF POWER MODULE – NO INTERFERENCE PROBLEM IN SHUTTLE BAY • EASIER TO HANDLE LARGE ITEMS OF EQUIPMENT (FROM OUTSIDE INSTEAD OF INSIDE) • COMPLIES WITH SPACE SHUTTLE INTERFACE REQUIREMENTS
DISADVANTAGES	• REQUIRES EXTENSIVE REWORK; REDUCTION IN LENGTH TO AVOID INTERFERENCE PROBLEMS IN SHUTTLE BAY. REMOVAL AND REFITTING OF EQUIPMENT • NO EXISTING TOOLING. DIFFICULT TO REPEAT • NO STRUCTURAL ANALYSIS AVAILABLE • NOT TESTED OR QUALIFIED FOR SPACE SHUTTLE • DIFFICULT FOR REMOVING/REPLACING LARGE ITEMS OF EQUIPMENT	• COST OF NEW DESIGN, TOOLING, TESTING, AND QUALIFICATION • REQUIRES NEW HANDLING EQUIPMENT	• SOME STRUCTURAL REWORK REQUIRED TO ADAPT FOR • POWER MODULE

- A comparative evaluation of open truss and shear box structural concepts for the solar array support assembly is summarized in this chart. While the open truss construction requires less weight, the shear-box construction is considered to have overriding advantages.

- The comparative advantages/disadvantages reflect experience on many satellite programs. They are especially pertinent to multipurpose satellites where program-peculiar equipment installations are difficult to predict.

Reference: Engineering Memo No. C-1.2.1-101, "Solar Array Support Structure Trade Study," dated 5/26/78.

SOLAR ARRAY SUPPORT STRUCTURE CONCEPTS

	CONCEPT I OPEN TRUSS	CONCEPT II ENCLOSED SHEAR BOX
		
WEIGHT	446 LBS	490 LBS
CONFIGURATION ADVANTAGES	• LIGHTER WEIGHT	• GREATER GROWTH POTENTIAL TO ACCOMMODATE ADDITIONAL EQUIPMENT • MORE EFFICIENT LOAD CARRYING SIMPLIFIES PRODUCIBILITY • ENVIRONMENTAL PROTECTION
CONFIGURATION DISADVANTAGES	• LESS EFFICIENT FOR ADDITIONAL EQUIP INST. • COMPLICATED JOINTS WITH MAIN STRUCTURE • LESS EFFICIENT LOAD CARRYING AND CONTINUITY • UNECONOMICAL USE OF VOLUME SPACE	• GREATER WEIGHT

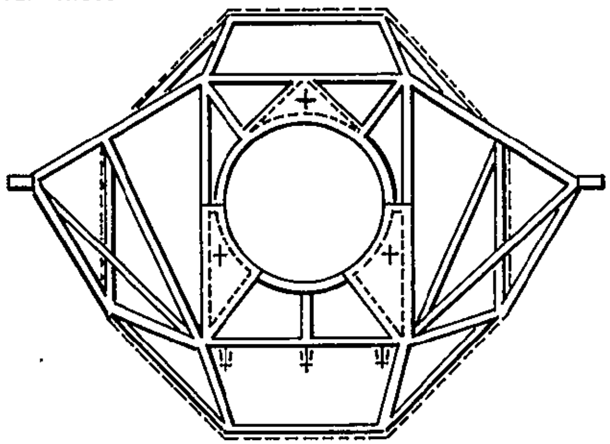
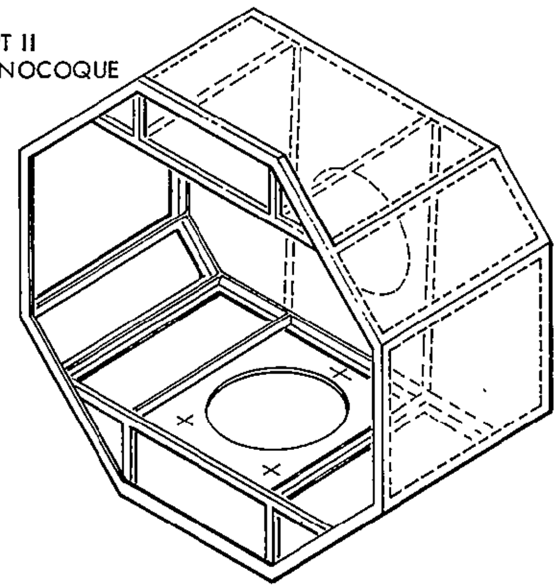
- Two alternative structural concepts for the docking collar structure open truss and semimonocoque, are illustrated and evaluated on this chart.

- The semimonocoque shows significant advantages over the open truss, i.e. a stiffer structure, greater growth potential for additional equipment, and environmental protection. It also permits accommodations of the third docking collar without severely impacting load paths and structural weight.

- The apparent advantage of lower weight for the open truss could easily be negated by requirements for secondary structure for equipment mounting and environmental protection.

References: LMSC EM No. C-1.2.1-102, "Structural Subassembly Trade Studies," dated 6/15/78.

BERTHING SYSTEM – SUPPORT STRUCTURE CONCEPTS

	CONCEPT I OPEN TRUSS	CONCEPT II SEMIMONOCOQUE
		
WEIGHT	<u>366 LBS</u>	<u>450 LBS</u>
CONFIGURATION ADVANTAGES	• LIGHTER WEIGHT • SIMPLIFIED DESIGN OF BASIC STRUCTURE	• GREATER GROWTH POTENTIAL TO ACCOMMODATE ADDITIONAL EQUIPMENT. • MORE ADAPTABLE TO IVA. • MORE EFFICIENT LOAD CARRYING STRUCTURE. • OFFERS ENVIROMENTAL PROTECTION. • MINNUM TOOLING REQUIRED FOR PRODUCTION.
CONFIGURATION DISADVANTAGES	• COMPLICATED JOINTS WITH MAIN BODY STRUCTURE. • LESS EFFICIENT LOAD CARRYING AND CONTINUITY. • LOW GROWTH POTENTIAL. • LESS EFFICIENT FOR EQUIPMENT INSTALLATION AND PROTECTION FROM THE ENVIROMENT.	• GREATER BASIC WEIGHT THAN TRUSS STRUCTURE.

- Major structural/material advances have been occurring from 1975 and will continue through 1980. While the baseline power module design is emphasizing available hardware economies, future growth concepts will benefit (on a cost vs. effectiveness basis) from incorporation of these ongoing (and future) technology advances.

- The chart illustrates a phase of technology available for new vehicle starts between 1980 and 1985 tied to organic composites, which is estimated to result in a 15 percent reduction in structural weight.

- Also shown is a further improvement achievable with metal matrix composites, with 30 percent weight reductions, during 1985 to 1990.

STRUCTURAL TECHNOLOGY GROWTH

STRUCTURAL COMPONENT	1978 TO 1980	1980 TO 1985		1985 TO 1990	
	PRESENT PM PROTOTYPE	CHANGE: 30% OF STRUCTURE MADE FROM ORGANIC COMPOSITE MATERIAL	BENEFITS	CHANGE: 25% OF STRUCTURE MADE FROM METAL MATRIX COMPOSITES	BENEFITS
FASTENERS AND/OR ATTACHMENT TECHNIQUE	ALUM RIVETS STEEL BOLTS/NUTS WELDING	TITANIUM FASTENERS BONDING	15% REDUCTION IN WEIGHT • THERMAL DIMENSIONAL STABILITY • INCREASED STIFFNESS EFFICIENCY • HIGH SPECIFIC STRENGTH • GOOD DIEELECTRIC STRENGTH (K-49) • GOOD FATIGUE RESISTANCE • GOOD THERMAL ISOLATION		30% DECREASE IN INITIAL WEIGHT • HIGH THERMAL AND ELECTRICAL CONDUCTIVITY • NO MOISTURE PICK-UP AND NO OUTGASSING • INCREASED STIFFNESS EFFICIENCY • HIGH SPECIFIC STRENGTH • GOOD FATIGUE RESISTANCE • LASER SURVIVABILITY • CONVENTIONAL FASTENING TECHNIQUES
TUBES/TRUSS MEMBERS	ALUM OR MAGNESIUM TUBING	GRAPHITE/EPOXY BY TUBE WINDING MACHINE		GRAPHITE/ALUMINUM; GRAPHITE/MAGNESIUM	
EXTRUSIONS	ALUMINUM MAGNESIUM	GRAPHITE/EPOXY BY PULTRUSION		GRAPHITE/ALUMINUM; GRAPHITE/MAGNESIUM	
MACHINED FITTINGS	ALUMINUM MAGNESIUM			GRAPHITE/ALUMINUM; GRAPHITE/MAGNESIUM	
BRACKETS	ALUMINUM/MAGNESIUM SHEET	THORNELL FABRIC			
PANELS	ALUMINUM/MAGNESIUM SHEET ALUMINUM HONEYCOMB	KEVLAR 49/T300/HMS WITH ALUMINUM HONEYCOMB CORE		GRAPHITE/ALUMINUM; GRAPHITE/MAGNESIUM FACE SHEETS	

STRUCTURES SUBSYSTEM-
CONCLUSIONS AND RECOMMENDATIONS

- NEW MAIN-BODY STRUCTURES, COMPATABLE WITH ORBITER ASCENT/LANDING CONDITIONS, MORE COST-EFFECTIVE THAN ATM SHOWN WITH THE BASELINE.
- MONOCOQUE/BOX-STRUCTURE MAJOR SUBASSEMBLIES ARE MORE COST-EFFECTIVE THAN TRUSS STRUCTURES.
- ORBITER ASCENT/LANDING CONDITIONS DICTATE MOST OF THE STRUCTURAL DESIGN. ON-ORBIT MANEUVER CONDITIONS IMPOSE VERY LIGHT LOADS.
- NO MAJOR RIGIDITY-REQUIREMENT CONDITIONS HAVE SURFACED AS POTENTIAL DESIGN CRITICAL CONSIDERATIONS.

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ELECTRICAL POWER SUBSYSTEM GROWTH

- As power level is programmed to grow to 200-250 kW by 1992, the increased demands can be met by increasing system size and utilizing advances in technology.

- Three means for improving power density and packaging efficiency for solar arrays are projected:

  Improvement of cell efficiency
  Replacement of silicon by higher efficiency (up to 20%) gallium arsenide
  Decreased panel density from 0.2 to 0.1 pounds/sq ft

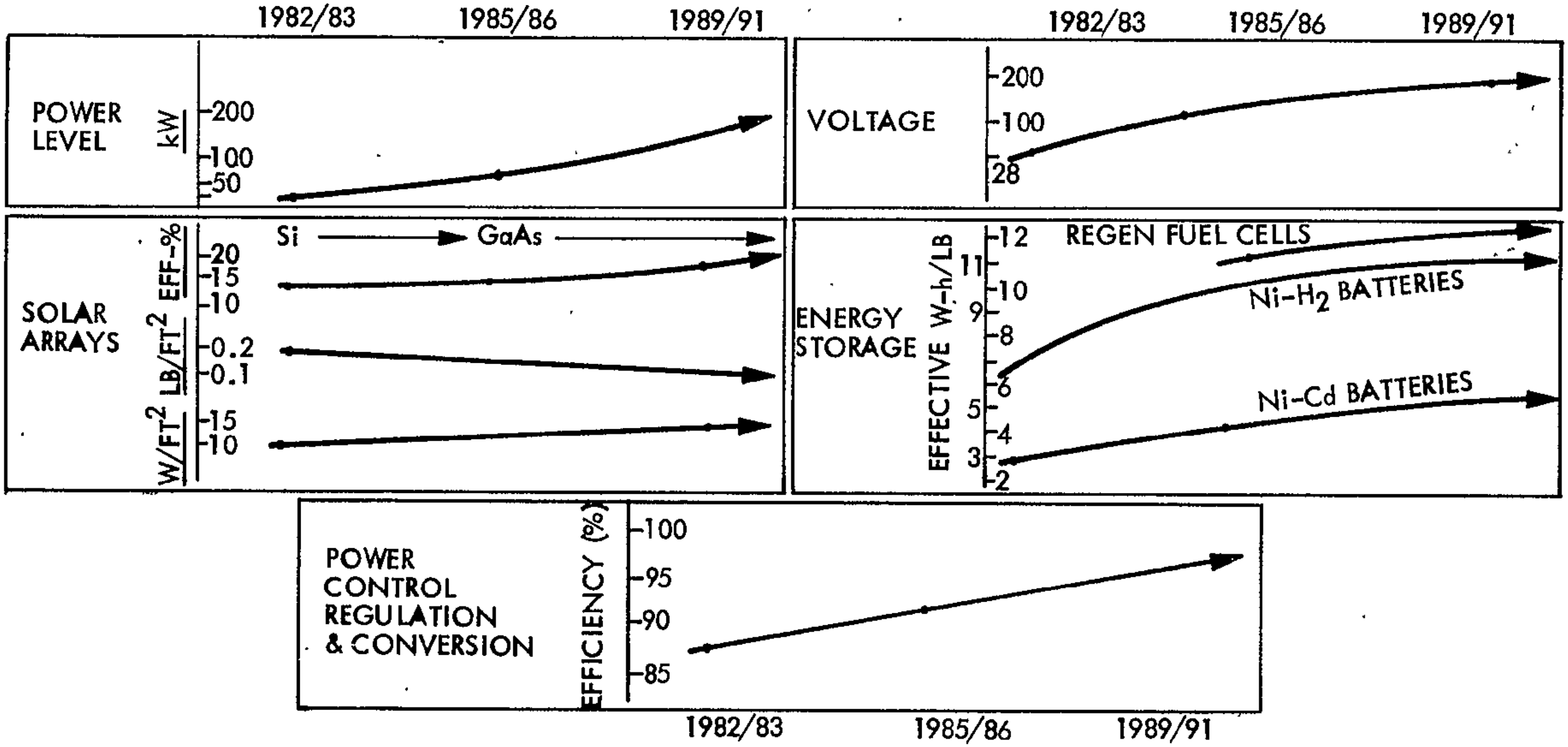
- Energy storage effective density is seen to gain significantly in going to $Ni\text{-}H_2$ batteries or regenerative fuel cells from Ni-Cd batteries. The improvement is due to both increasing packaging density and depth of discharge (DoD).

- Regenerative fuel cells are shown with a small weight advantage over $Ni\text{-}H_2$ batteries, however, a slight increase in battery DoD would cancel this difference.

- The power control and conditioning equipment efficiency is shown to increase with time. This is attributed to operation at higher voltage levels, advancement in component technology, and improved circuit design.

- For 1986 and beyond, extensive use of graphite composites will be used for structural members, resulting in substantial weight reductions.

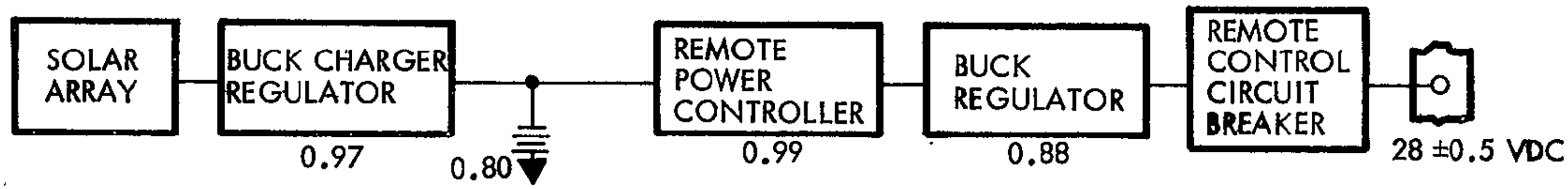
ELECTRICAL POWER SUBSYSTEM GROWTH CHARACTERISTICS



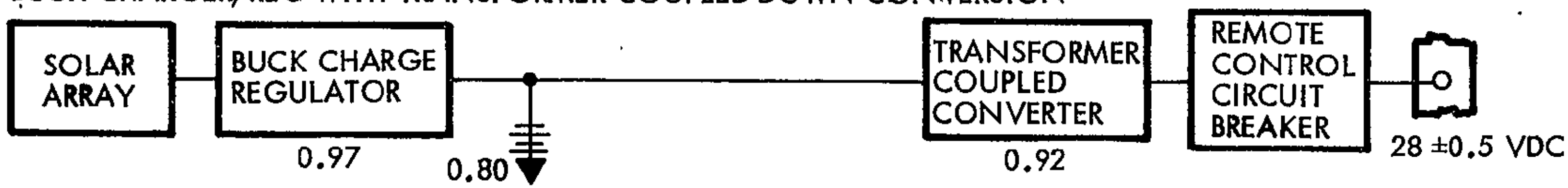
Four concepts were considered for the Electrical Power Subsystem (EPS) configuration trade. These represent the combination of the transformer coupled converter vs the buck regulator and cascaded power stages (charger and output regulator) vs direct transfer (regulation) of solar array power to the bus. The efficiency values for trades are based on actual test results, in the case of the buck charger regulator, and a detailed analytical model for the TCC.

ELECTRICAL POWER SUBSYSTEM CONFIGURATIONS

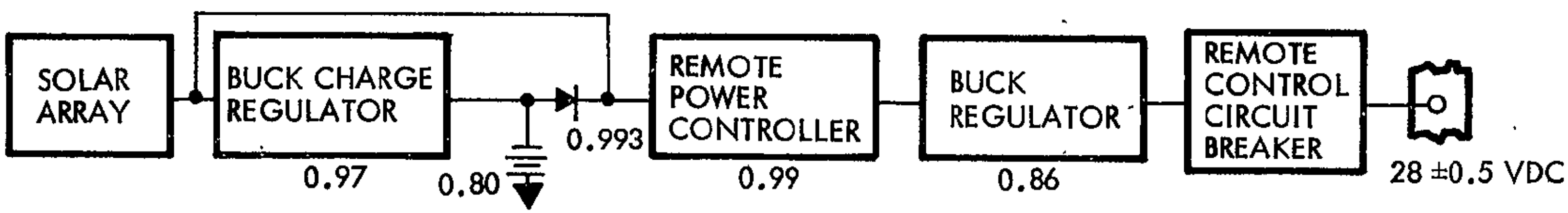
(1) BUCK CHARGER/REGULATOR WITH BUCK DOWN CONVERSION



(2) BUCK CHARGER/REG WITH TRANSFORMER COUPLED DOWN CONVERSION



(3) LMSC – DIRECT TRANSFER/COMMON (BUCK) REGULATOR

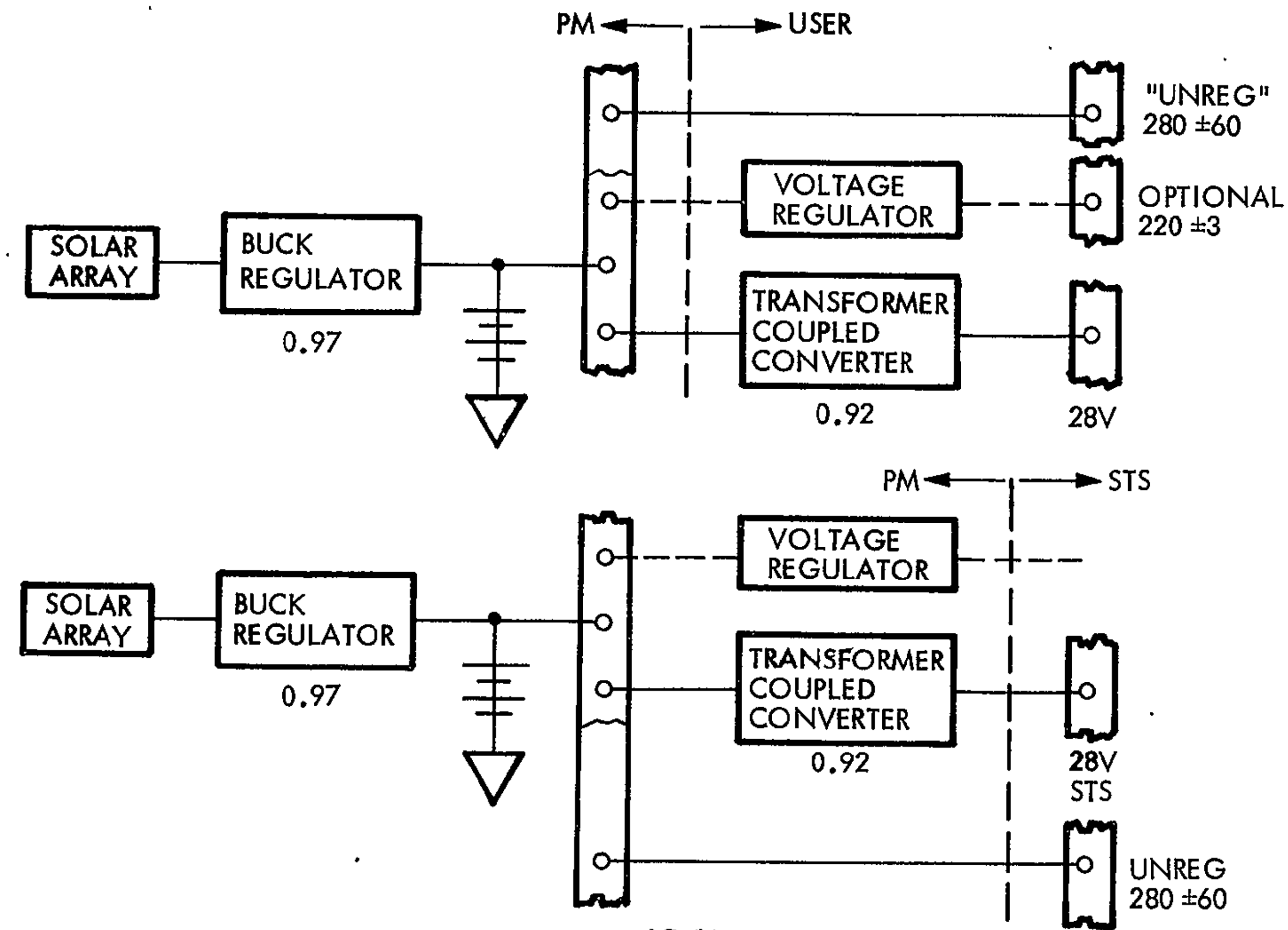


(4) LMSC – DIRECT TRANSFER/TRANSFORMER COUPLED DOWN CONVERSION

The 140 Vdc approach, identified by several agencies as the best approach for 25 to 35 kW power systems, is scalable at reasonable efficiencies to ten times that level or more (300 kW). It is not apparent that higher control efficiency can be obtained at higher voltage for a large space power system of the multi-hundred kilowatt scale. The efficiency of thyristor based power electronics will not match that of the 140 Vdc system below several kilovolts of bus voltage level although distribution weight improvements may be sufficient to warrant still higher voltages. It is projected that the efficiency of the regulator concepts will improve by doubling the 140 Vdc level between now and 1990 as a result of component improvements and low IR losses. This may be the practical limit for transistor systems.

ELECTRICAL POWER SUBSYSTEM GROWTH
HIGH VOLTAGE CONFIGURATION

PROJECTED 1990



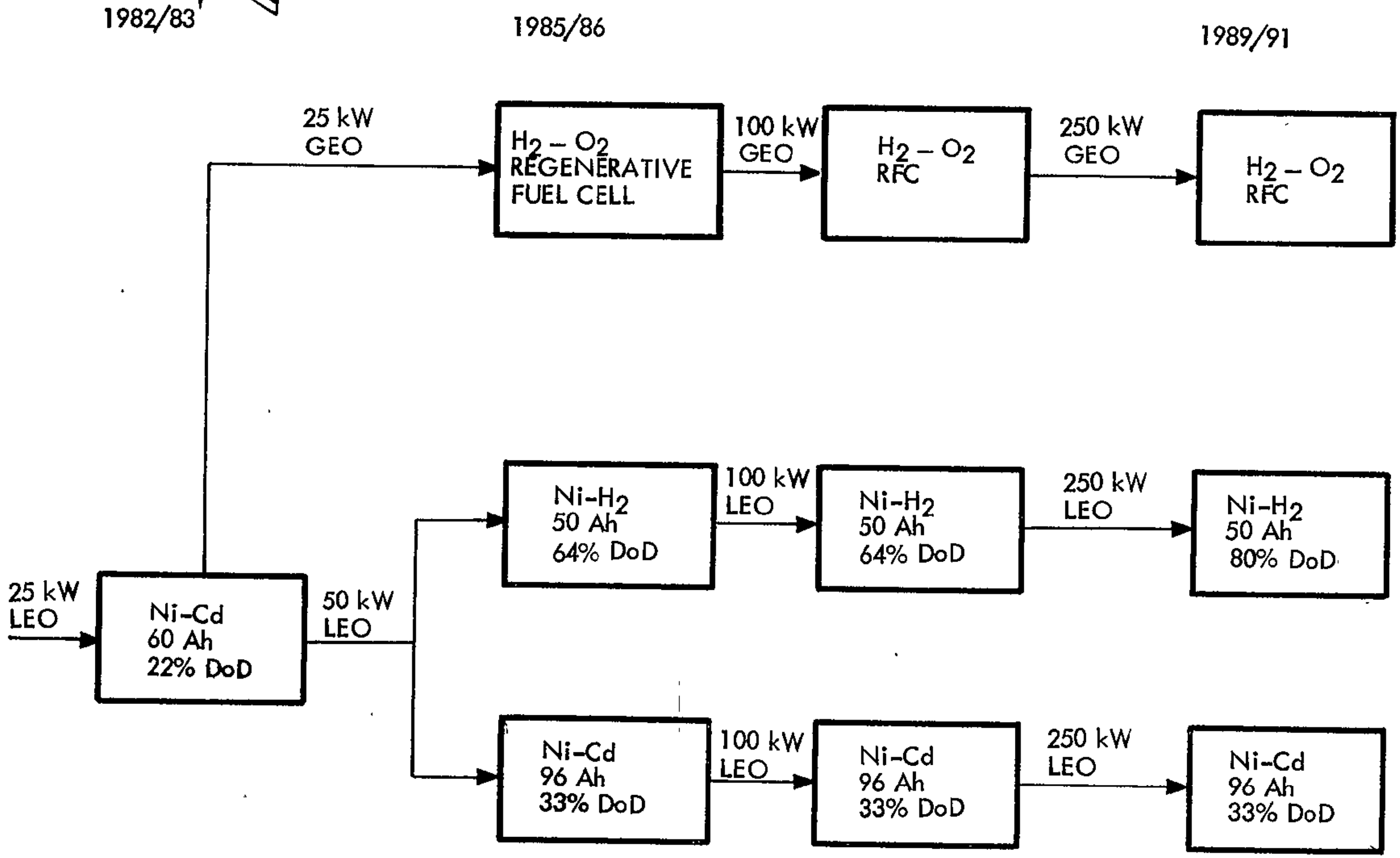
- The present baseline Ni-Cd battery system using 12 - 110 cell, 60 AH batteries operated to 22% DoD, is cost effective and reliable for the first PM, regardless of subsequent energy storage system selection.

- Early requirements for geosynchronous missions would prompt the development of a regenerative fuel cell system, because of its light weight and the delivery cost to high orbit. Once the nonrecurring costs have been assimilated, the recurring costs for regenerative fuel cells are approximately the same as for nickel-hydrogen batteries operated to 64% DoD.

- This diagram indicates that if the needs are restricted to LEO, the choice remains between 64% DoD Ni-H_2 and 33% DoD, 96 AH (nominal 100 AH) Ni-Cd batteries. Ni-H_2 is favored because as this technology matures, even higher DoD capability is expected.

- The material used in the trade analysis of the energy storage system is treated in detail in LMSC EM No. C-1.2.5-101.

ELECTRICAL POWER SUBSYSTEM EFFECTIVE GROWTH ALTERNATIVES FOR ENERGY STORAGE



- Advances in technology will allow for significant power system growth within present Shuttle weight and volume constraints. In 1983, 50 kW capability can be provided using present baseline equipment, with all power provided to 28 volt regulated buses.

- By 1986, lighter-weight and efficient solar arrays are projected with nickel-hydrogen batteries operating to 64% DoD. The Ni-H_2 technology is advancing rapidly, therefore, early initiation of a development and life test program should yield high confidence in this battery before commitment to flight. Supplying power at 110V provides significant economy in all aspects of power management. The dc/dc converters are sized to maximum current, therefore, higher voltage allows a higher power rating per unit as well as higher efficiency. Power distribution and cabling also benefit from higher voltage; weights at 125 kW are not greater than for the 50 kW system, which are based on ATM estimates.

- Projections for 1990 call for going to higher efficiency GaAs solar cells built into a light-weight 0.1 lb/ft^2, solar array. Present test programs for Ni-H_2 battery cells show 80% DoD capability at LEO. By 1990 it is expected that lighter-weight Ni-H_2 cells will have demonstrated high reliability at 80% DoD. Increasing voltage to 220V will permit weight savings in electronics, power distribution, and cabling. Gains in regulator and converter efficiency are reflected in lighter electronics weight and in reduced solar array area.

ELECTRICAL POWER FOR SUBSYSTEM GROWTH
LEO SYSTEMS

	CURRENT TECHNOLOGY				1990 TECHNOLOGY	
POWER	25 kW	50 kW	100 kW	200 kW	100 kW	200 kW
CELL TYPE, LB/FT^2	Si, 0.2	Si, 0.2	Si, 0.15	Si, 0.15	GaAs, 0.1	GaAs, 0.1
BATTERY, DoD	NiCd, 22%	NiCd, 22%	NiH_2, 40%	NiH_2, 64%	NiH_2, 80%	NiH_2, 80%
VOLTAGE	28	28	110	110	110	220
WEIGHTS – LB						
SOLAR ARRAY	2,400	4,850	8,900	17,700	5,500	11,000
BATTERIES	7,440	14,880	12,800	16,000	6,400	12,800
ELECTRONICS	1,320	2,640	2,400	4,800	2,400	2,400
POWER DISTRIBUTION	250	470	600	1,200	750	1,500
CABLING	600	800	1,000	2,000	1,000	1,500
SUB TOTAL	12,010	23,640	25,700	41,700	16,050	29,200
CONTINGENCY, 25%	3,003	5,910	6,500	10,500	4,012	7,300
TOTAL	15,013	29,550	32,200	52,200	20,062	36,500

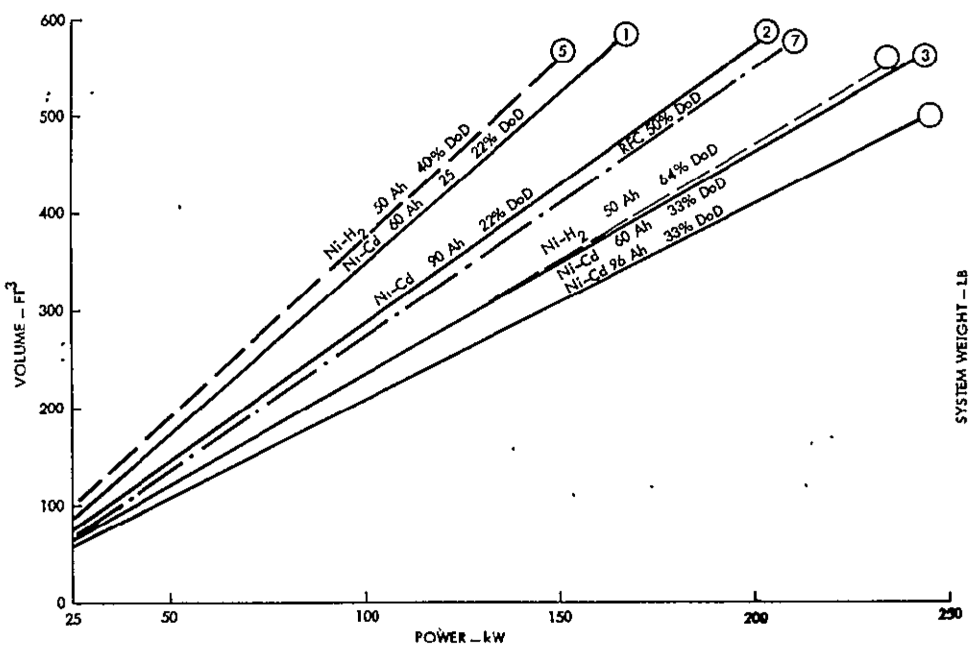
ENERGY STORAGE SYSTEM: VOLUME VS. POWER

- The graph indicates for like capacity, Ni-H_2 occupies more volume than Ni-Cd batteries and some volume is saved by going to larger cells. But the biggest gain develops from going to greater DoD. Since nickel-hydrogen batteries indicate higher DoD capacibility than Ni-Cd, the Ni-Cd volumetric advantage is marginal. The regenerative fuel cell system volume could be made smaller by increasing reactant storage tank pressure from 400 psi, but that would increase electrolyzer operating pressure and weight. Volume requirements for energy storage remain a small percentage of Orbiter cargo bay volume, at 100 kW all systems fall between 2 and 4 percent of Orbiter cargo bay volume.

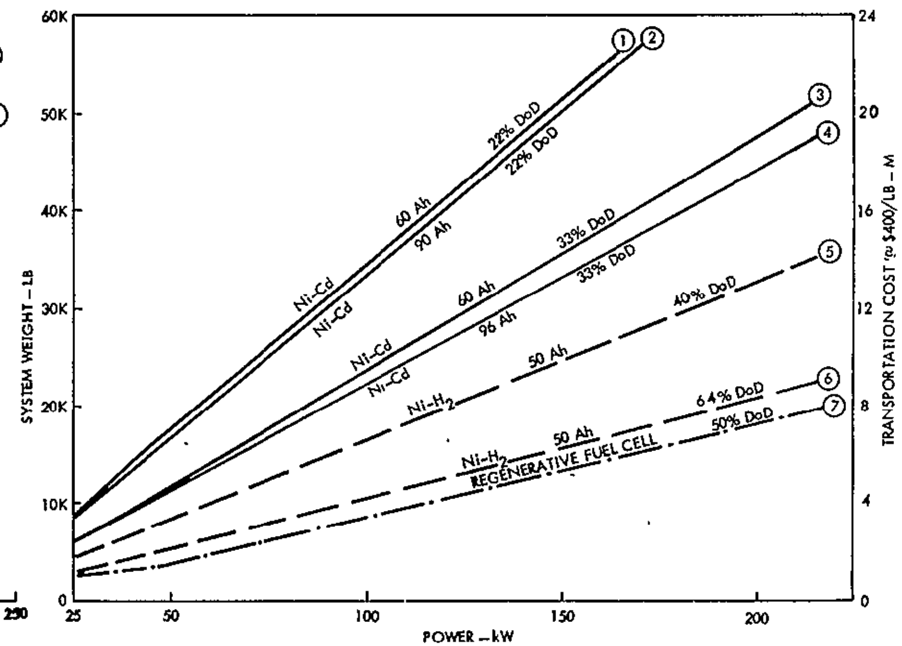
ENERGY STORAGE SYSTEM: WEIGHT VS. POWER

- Each alternative system is assumed linear in growth with power level. Major weight savings may be affected by either increasing DoD or changing electrochemical couples. Smaller weight savings may be gained by developing battery cells of larger capacity. Nickel-hydrogen batteries at 64 percent DoD, which is believed conservative for the long term, and regenerative fuel cell systems, offer significant weight savings. When transport cost to LEO are considered at \$400/lb, weight becomes a significant cost element.

ENERGY STORAGE SYSTEM
VOLUME AND WEIGHT VS POWER LEVEL



VOLUME Vs POWER



WEIGHT Vs POWER

COST VS POWER OUTPUT FOR A HYPOTHETICAL GROWTH SEQUENCE OF ALTERNATE ENERGY STORAGE SYSTEMS

- BASIS: The nonrecurring costs are added to the recurring costs for one 25 kW system. The 50 kW point is determined by adding the recurring cost of one 50 kW system to the first 25 kW PM costs. The 100 kW points add the recurring cost of one 100 kW system to the foregoing summation, and so on for the 200 kW point.

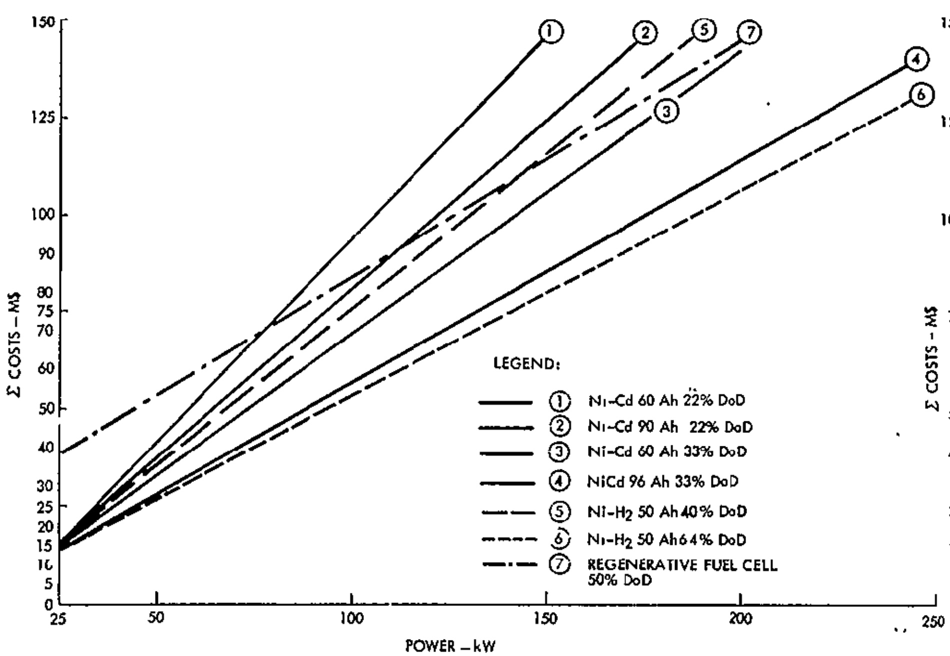
- ANALYSIS: The recurring cost slopes for 64% DoD Ni-H_2 and the RFC are approximately equal, and the 96 AH 33% DoD Ni-Cd slope is only slightly higher. This would indicate a first choice of Ni-H_2 followed by Ni-Cd, unless the high RFC nonrecurring costs can be amortized over more units.

COST VS POWER OUTPUT FOR SINGLE VEHICLE PROGRAMS

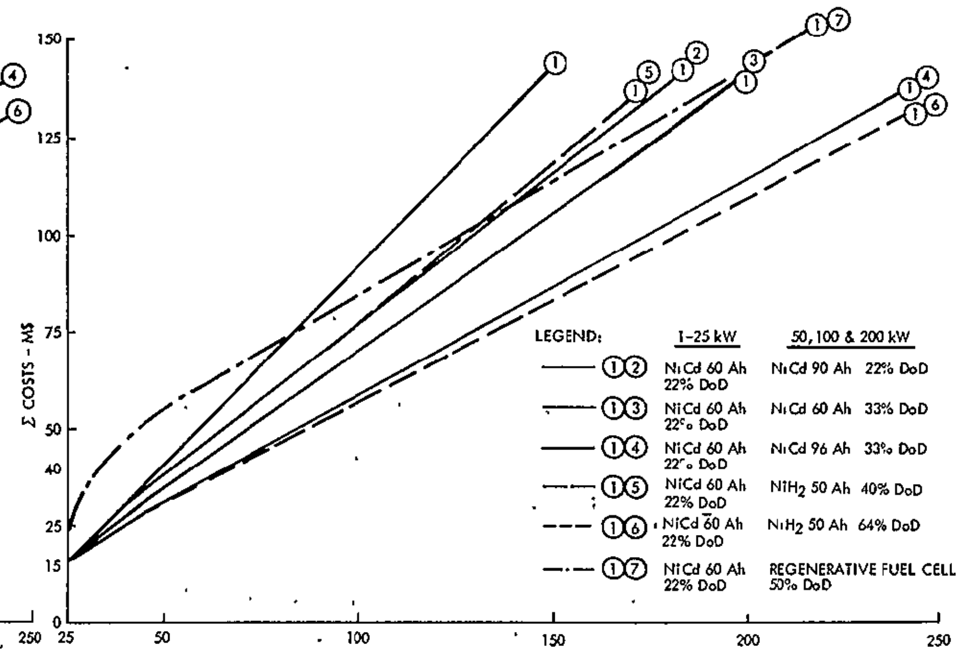
- BASIS: All alternative curves begin by using the same baseline Ni-Cd 60 Ah 22% DoD energy storage system for one 25 kW PM plus nonrecurring and recurring costs for one of each alternative system at 50, 100, and 200 kW.

- ANALYSIS: This set of curves does not differ significantly from the preceding case. There is a small penalty in accepting the baseline energy storage system for usage on the first 25 kW PM, and then developing a more cost-effective system for subsequent PMs.

ENERGY STORAGE SUBSYSTEM COSTS



COSTS FOR 25, 50, 100 & 200 kW POWER MODULES



COSTS FOR BASELINE 25 kW FOLLOWED BY ALT 50, 100 & 200 kW SYSTEMS

- Two factors make the regenerative fuel cell system especially attractive. First, it is approximately one-half the weight of the $Ni-H_2$ system and one-third the weight of the Ni-Cd system. Secondly, the high cost of transportation to GEO gives the RFC the lowest recurring cost. The higher nonrecurring development cost of the RFC would be recovered in two or three flights.

- For the GEO, because of the low-cycle life required, allowable DoD for the batteries was increased to 60 and 80%, respectively, for Ni-Cd and $Ni-H_2$ batteries, based on a maximum eclipse of 1.2 hours. The long recharge time reduces electrolyzer requirements, therefore, only two 28-volt modules are required.

- If the RFC is developed for GEO, its recurring costs are competitive with the $Ni-H_2$ battery for LEO applications.

ENERGY STORAGE TRADE TREE FOR 25 kW POWER SUBSYSTEM – GEO

	NiCD BATTERIES	NiH_2 BATTERIES	REGENERATIVE FUEL CELLS	
			FUEL CELLS	ELECTROLYZERS
	60% DOD	80% DOD		
	90 Ah	50 Ah	15 kW	3 kW
	6-110 CELL BATTERIES	8-105 CELL BATTERIES	3-128 CELL MODULES	2-17 CELL MODULES

SYSTEM	NiCD BATTERIES	NiH_2 BATTERIES	REGENERATIVE FUEL CELLS
WEIGHT – LB	6570	4529	2379
VOLUME – FT^3	66	99	112 (2)
COST – N.R. – \$M	3.26	3.76	27.06
RECURRING	5.83	8.97	9.95
TRANSPORT (1)	32.85	22.65	11.90
TOTAL	41.94	35.38	48.91
TOTAL W/O N.R.	38.68	31.62	21.85

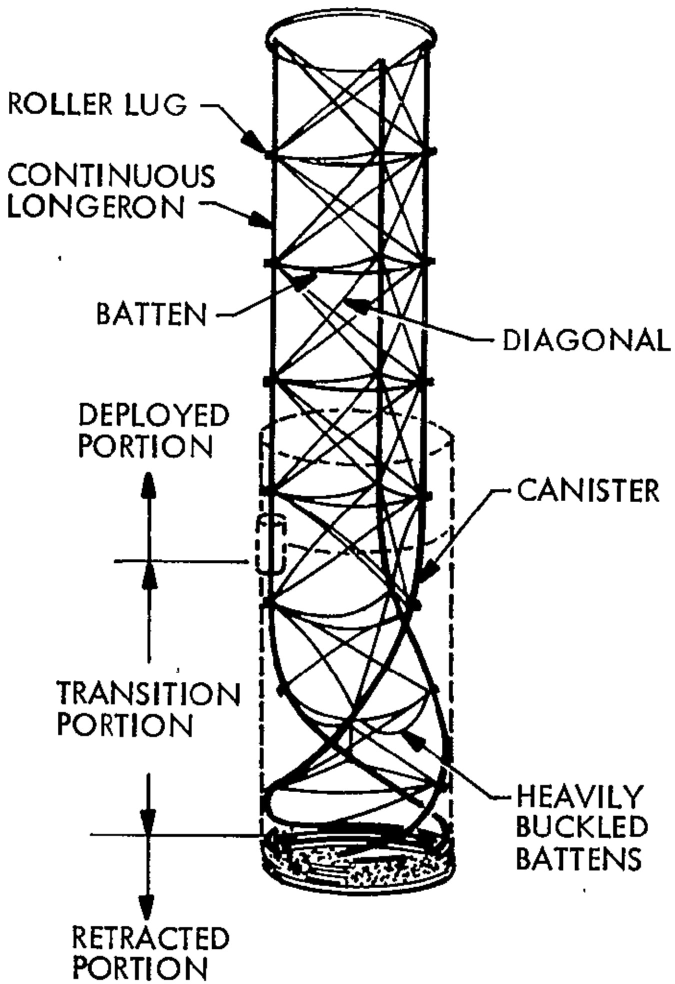
NOTES: (1) \$5,000/LB

(2) 400 PSI GAS STORAGE FOR 50% DOD

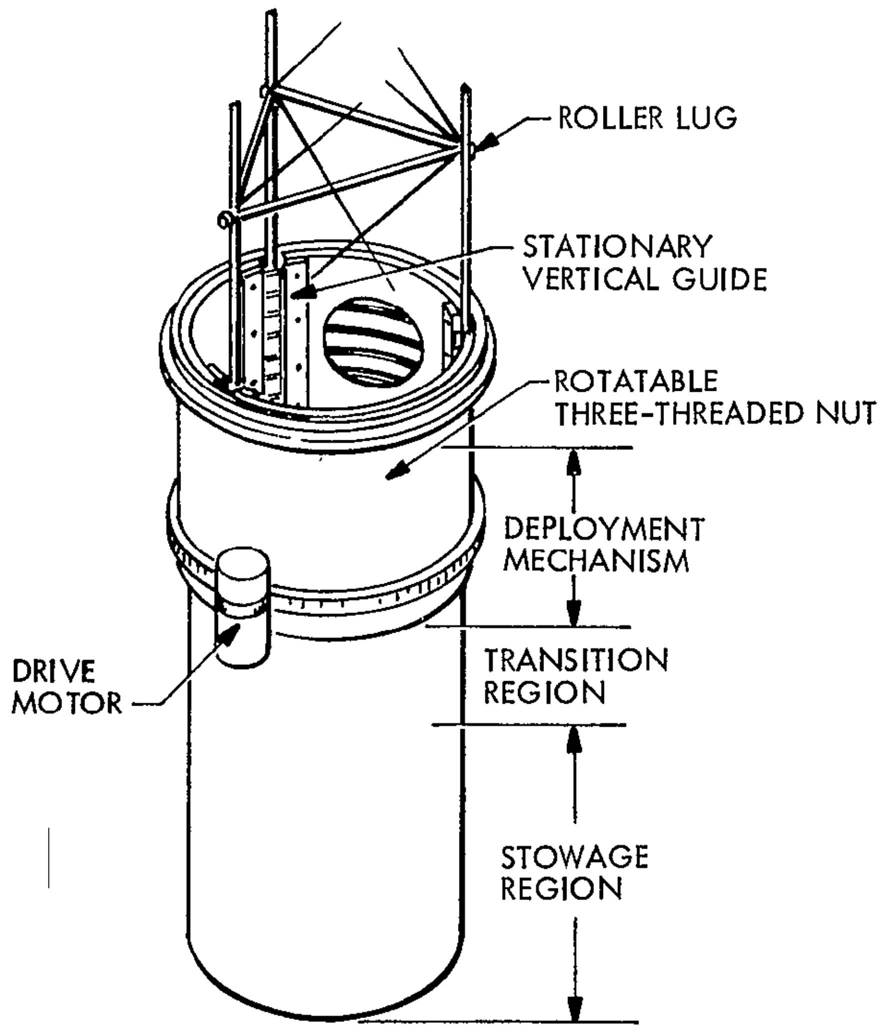
In order to determine the characteristics of the solar array system with respect to its dynamic response, LMSC has investigated the deployment mast design parameters. This effort has been completed in conjunction with Mr. R. Crawford of AEC-Able Engineering. The following charts present some of this parameter evaluation. LMSC has used this data to investigate the feasibility of a common building block concept for growth to higher power levels. The prime driver in this investigation is how these large deployment masts can be stowed and what solar array capabilities can be achieved given the volume limitation that we have within the Orbiter cargo bay. As a result of this study, it appears feasible to use a common MAST envelope for growth from 25 kW to 250 kW using a common physical blocking solar array system.

SOLAR ARRAY DEPLOYMENT MAST EVALUATIONS

DEPLOYMENT GEOMETRY AND NOMENCLATURE FOR CONTINUOUS-LONGERON LATTICE BOOMS



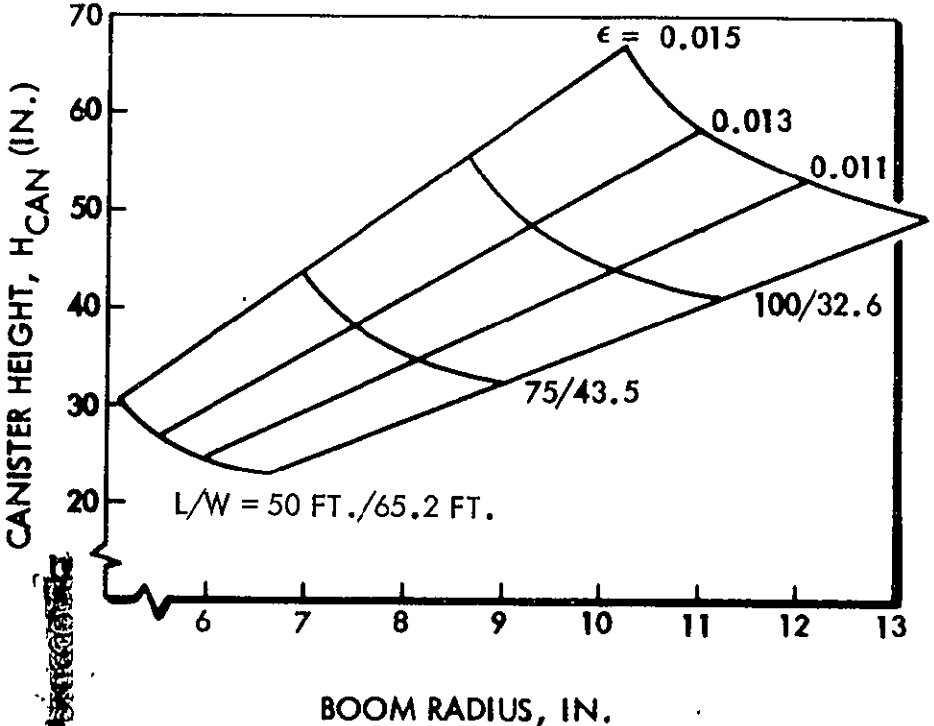
CANISTER FOR DEPLOYING AND SUPPORTING CONTINUOUS-LONGERON LATTICE BOOMS



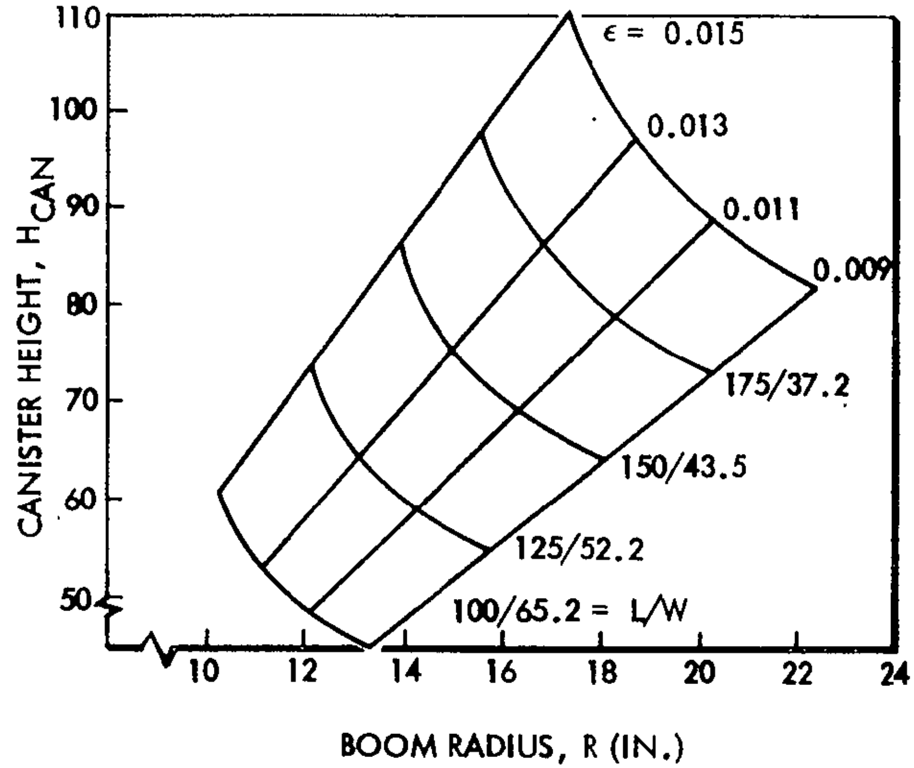
PM (25kW) DEPLOYMENT MAST CHARACTERISTICS

PM (25 - 50 kW)

30 KW/WING



60 KW WING



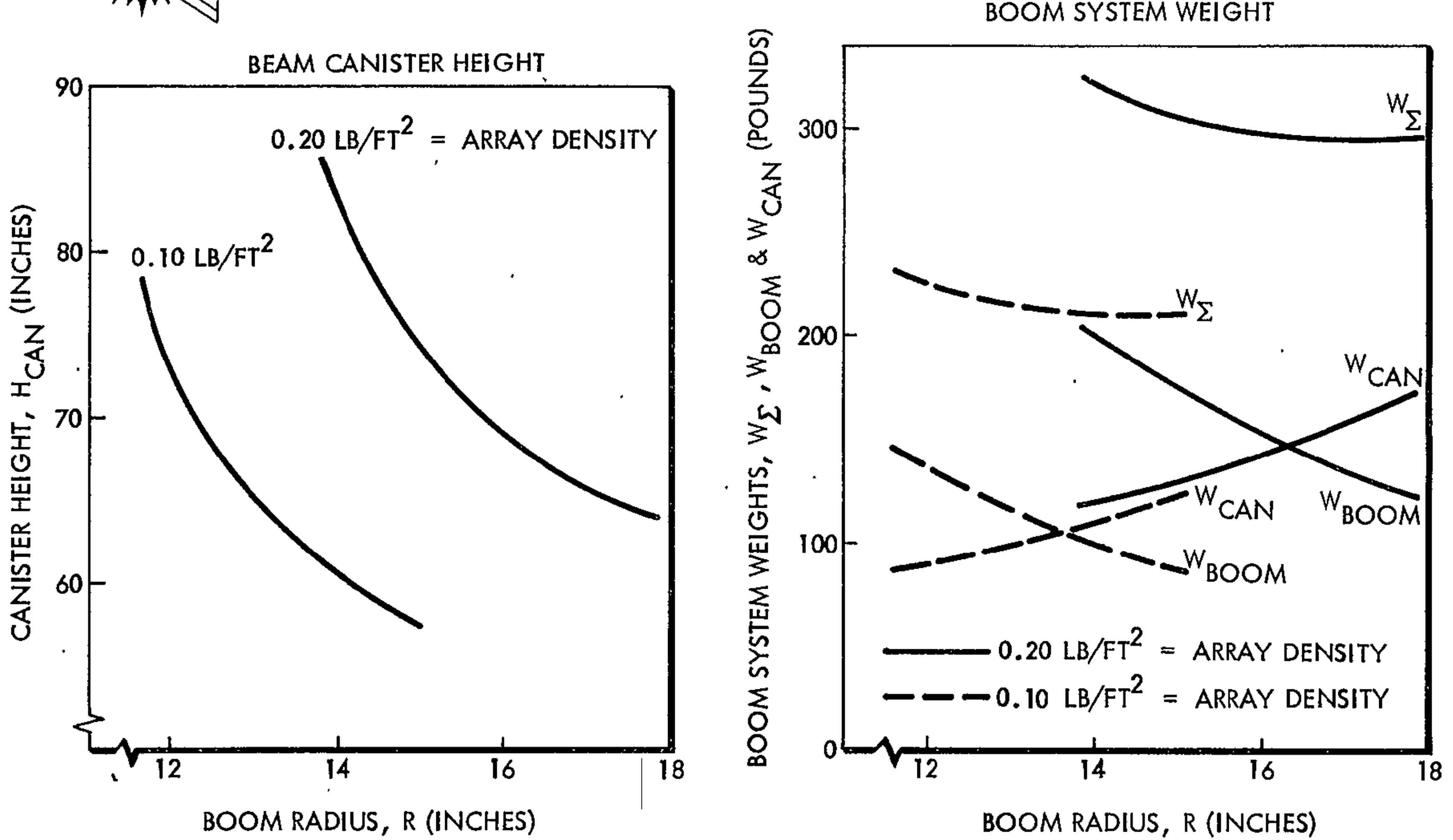
CANISTER HEIGHT AS A FUNCTION OF BOOM RADIUS

ρ = 0.2 LB/FT^2

f = 0.04 Hz

ϵ = STRAIN IN LONGERON MATERIAL

MAST CHARACTERISTICS FOR GROWTH



S/A = 25,000 FT^2 (4 WINGS)

f_n = 0.04 HZ

L = 150 FT

W = 41.67 FT

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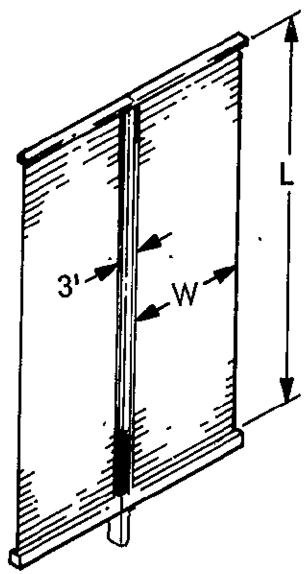
The basic solar array building block blanket sizes used to develop the growth configurations presented are shown in the chart. The 25 kW PM uses the 13.2 ft wide blanket. All systems, 50 kW to 250 kW, use a wider and longer basic blanket as shown. One radiator option is indicated where the radiator panels extend perpendicular to the back side of the solar arrays.

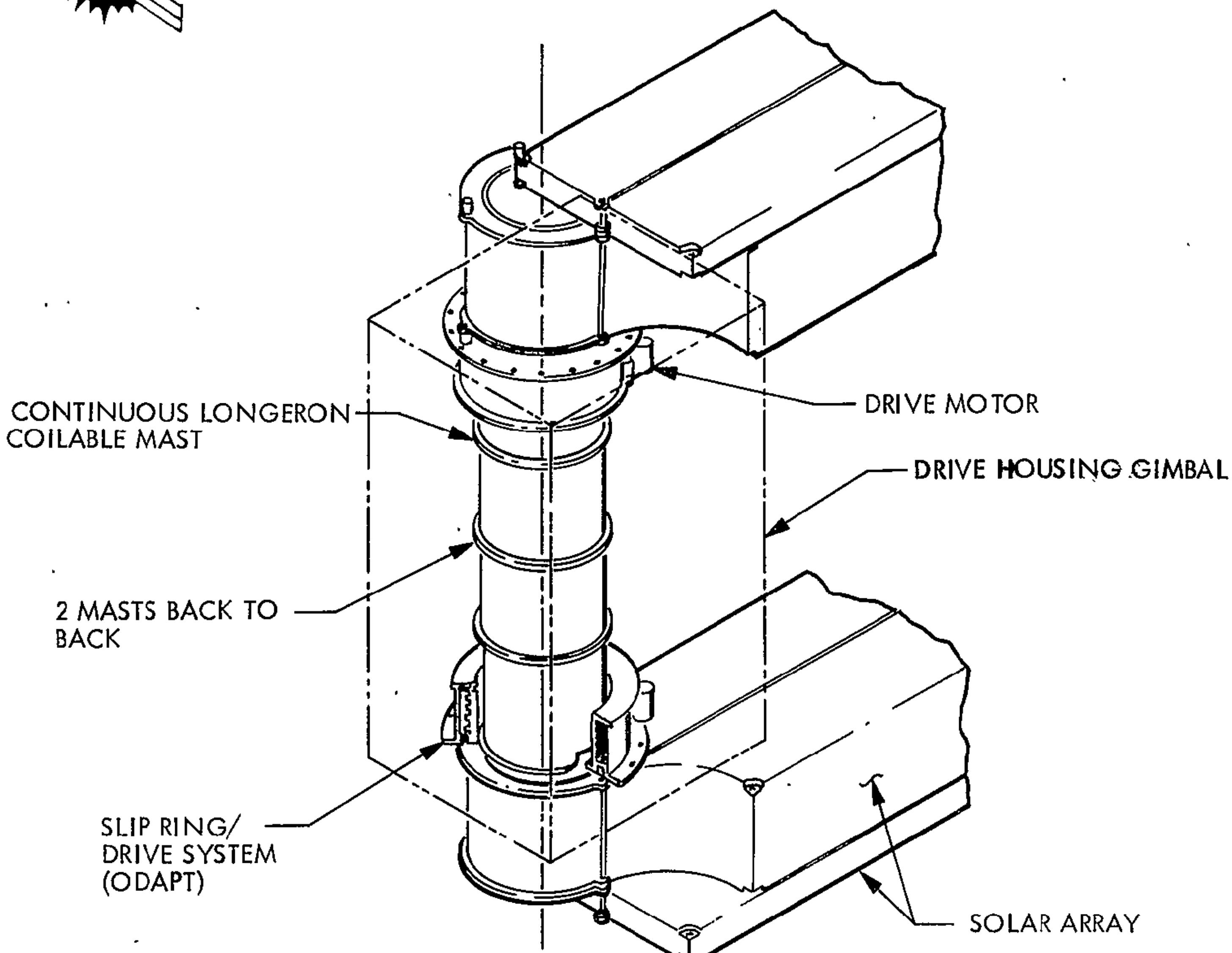
BASIC SOLAR ARRAY BUILDING BLOCK FOR GROWTH COMMONALITY



CHARACTERISTICS				
	25 kW	50 kW	100 kW	200 kW
BLANKET WIDTH (FT)	13.2	19.8	19.8	19.8
BLANKET LENGTH (FT)	130	172	172	172
BLANKET AREA (FT^2)	1700	3400	3400	3400
NUMBER OF BLANKETS	4	4	8	16
TOTAL AREA (FT^2)	6800	13,600	27,200	54,400

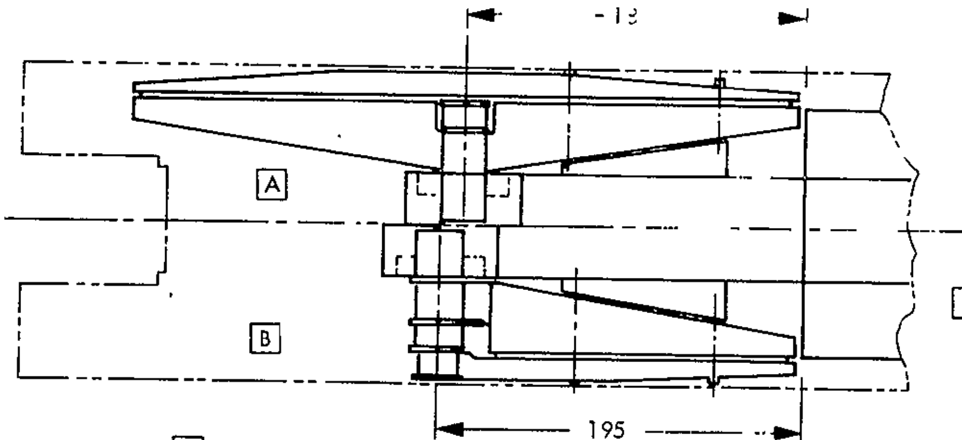
LMSC has developed a set of baseline requirements to determine the drive system characteristics. Using these requirements and the basic installation concepts, Ball Aerospace System Division (BASD) has provided LMSC with a baseline design and supporting comparative component analysis. The basic drive system and power transfer assembly for both solar array sides are estimated to weigh 300 to 400 lbs, depending on redundancy and built-in growth capabilities. This effort is a direct off-shoot of the Orientation Drive and Power Transfer Assembly (ODAPT) technology BASD developed for NASA under subcontract to LMSC. In fact, the outer gimbal of the Space Station Solar Array is nearly identical in size to the drive required for the PM mast axis drive. Therefore, considerable knowledge has been developed on this size ODAPT and is directly applicable to minimize PM effort.

SOLAR ARRAY ODAPT ASSEMBLY



Solar array installation and design layout were studied to develop comparisons between alternative arrangements. Six arrangements, as shown on LMSC Drawing SK 48700, were conceived and studied. These configurations ranged from the MSFC baseline fixed solar array to those that are folded and capable of growth to 65 kW Power Modules. This study assumed that the solar array must have a first mode bending frequency close to 0.04 Hz. In addition, the largest feasible MAST configuration was investigated which would provide for slightly greater stiffness. The folded solar array was estimated to be lighter than the MSFC baseline because of the structural efficiency, particularly when caged for launch. This configuration also minimizes protrusion into the Airlock/MMU regions. Based on this study, LMSC prefers the folded configuration over the fixed arrangement. The fixed versus folded solar array systems are shown along with the largest MAST investigated.

SOLAR ARRAY CONFIGURATION STUDY



A

ESTIMATED WEIGHTS (LB)

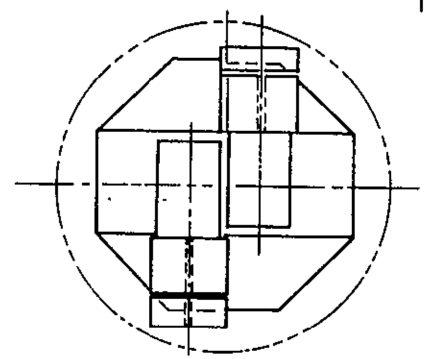
RIGID CONTAINER DESIGN

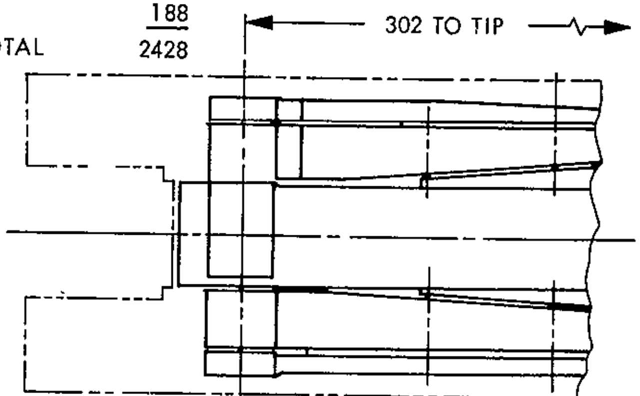
• BLANKETS	1380
• MASTS (11R X 71 LG CAN)	400
• CONTAINER	440
• DRIVE	130
• DRIVE HOUSING	188
TOTAL	2538

B

FOLDED CONTAINER DESIGN

• BLANKETS	1380
• MASTS (11 R X 71 LG CAN)	400
• CONTAINER	330
• DRIVE	130
• DRIVE HOUSING	188
TOTAL	2428





3850 SQ FT BLANKET WITH 15 INCH RADIUS MAST

EPS - CONCLUSIONS

- SOLAR ARRAY CAN BE SCALED TO 250 kW POWER LEVEL WITH BUILDING BLOCK CONCEPT(S)
- NiH_2 BATTERIES PROVIDE SUFFICIENT WEIGHT SAVINGS TO MERIT IMMEDIATE DEVELOPMENT FOR NASA HIGH-POWER LEO MISSIONS AS EARLY AS 1986
- INITIAL BUILDING BLOCK CONCEPT MINIMIZES RDT&E TO ACCOMMODATE SOLAR ARRAY SYSTEM GROWTH
- ADVANTAGES OF TCC OVER BUCK REGULATOR WARRANTS ITS USE FOR POWER MODULE
- SOLAR ARRAY DEPLOYMENT MAST CAN PROVIDE SUFFICIENT STIFFNESS TO MEET AT LEAST A 0.04 Hz FREQUENCY REQUIREMENT AT LENGTHS TO 150 FEET

EPS-ANALYSIS RESULTS/RECOMMENDATIONS

ENERGY STORAGE

- USE Ni-Cd BATTERIES OF 20-25 PERCENT DOD FOR FIRST 25 kW SYSTEM
- INITIATE N I-H_2 BATTERY DEVELOPMENT AND LIFE TEST PROGRAM FOR LATER POWER MODULES AND/OR REFURBISHMENT MODES
- INITIATE REGENERATIVE FUEL CELL STUDIES TO DEFINE REQUIREMENTS FOR FUEL CELLS AND ELECTROLYZERS AND PLAN DEVELOPMENT PROGRAMS

ELECTRICAL CONTROL EQUIPMENT/POWER CONDITIONING

- CONTINUE DEVELOPMENT TO IMPROVE SUBSYSTEM EFFICIENCY TO USE HIGHER VOLTAGES AS COMPONENT TECHNOLOGY ALLOWS
- USE UNREGULATED POWER FOR DISTRIBUTION WITH REGULATION SUPPLIED BY USER

SOLAR ARRAYS

- SELECT INITIAL SOLAR ARRAY CONFIGURATION THAT GIVES MOST FLEXIBILITY FOR EVOLUTION
- INITIATE . DYNAMIC ANALYSIS AND CONTROL STUDIES FOR LARGE AREA SOLAR ARRAY/SPACECRAFT CONFIGURATIONS

POWER MODULE THERMAL GROWTH ANALYSIS

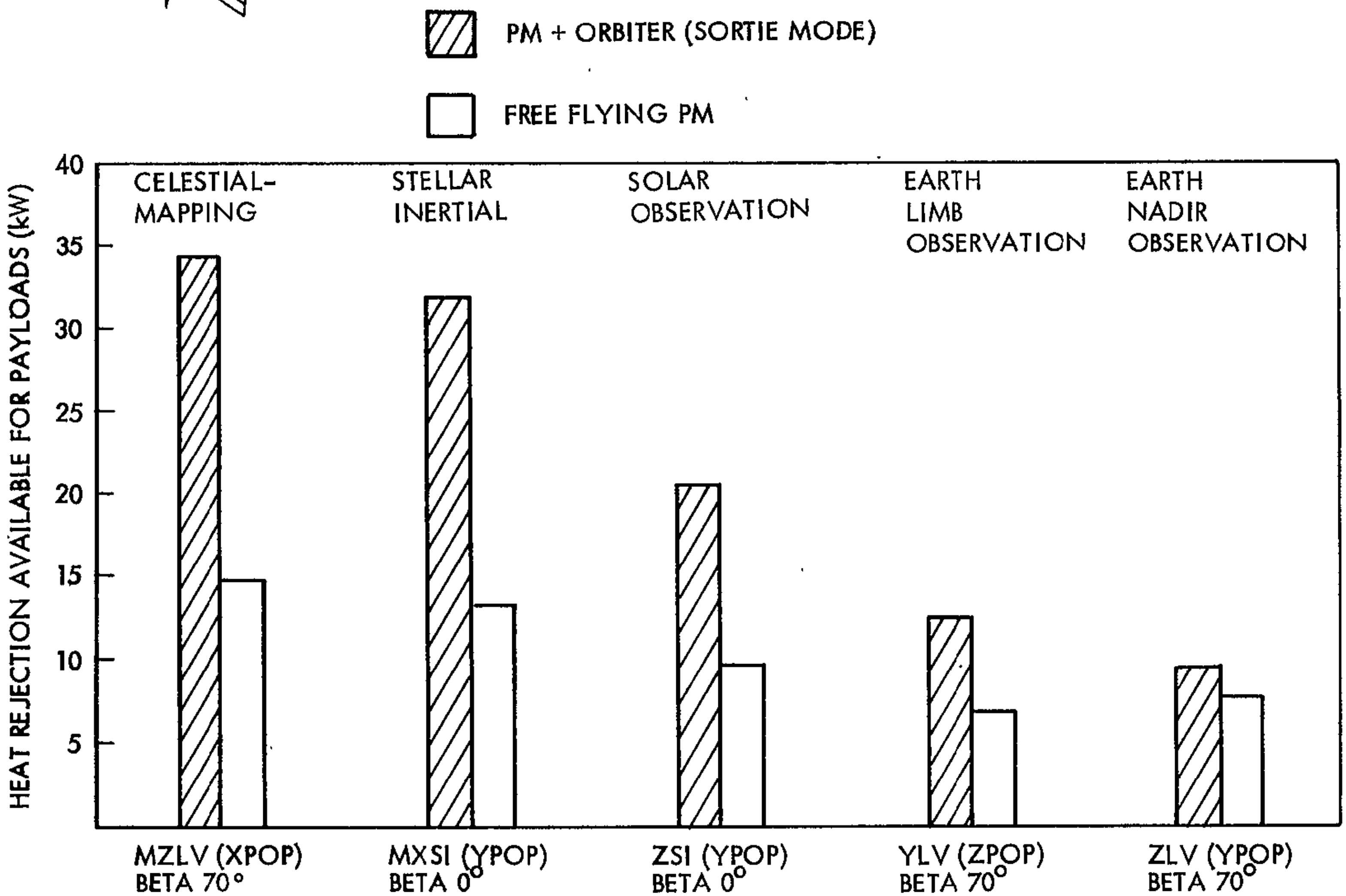
- The chart shows the heat rejection available to payloads with 25 kW (electrical) being supplied by the Power Module and with the Orbiter fuel cells and flash evaporator system not in operation. The Power Module heat rejection requirements of 9.0 kW and Orbiter requirements of 12.5 kW (in the powered-down mode) have been subtracted from the total radiator system capability. The five orbital environments shown are mission-representative and include the minimum and maximum radiator capabilities. The performance of the separate Power Module and Orbiter radiators is reduced from 5 to 10 percent (depending on orbit) when the two spacecraft are flown in the sortie mode.

- Later charts show the total variation of heat rejection capabilities for individual vehicle attitudes over a range of Beta angles. (Beta angle is the angle between the earth-sun line and the orbit plane.) The wide variation in radiator performance shown in this figure is the direct result of variations in the absorbed solar and earthshine energy and, to a lesser extent, the orientation of the Power Module solar arrays.

- The thermal analysis calculations apply to the baseline configuration with four Orbiter radiators on the PM – one on each Y-axis side and two extending from the plus Z-axis.

- The missions identified for each orbit attitude are based on an instrument field-of-view centered about the plus Z-axis.

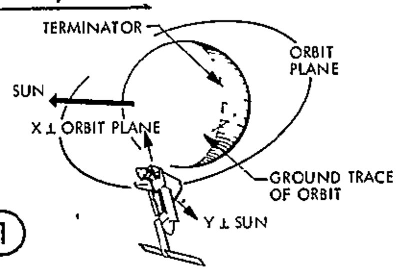
HEAT REJECTION AVAILABLE FOR PAYLOADS

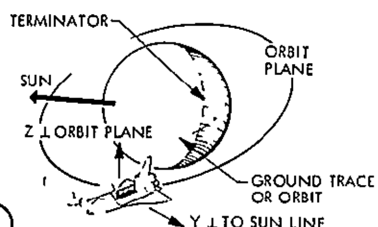


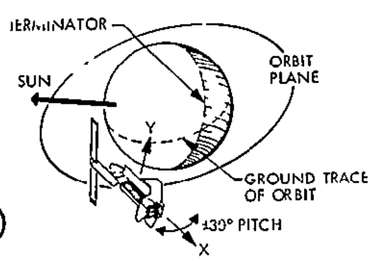
- Seven orbits were chosen for mission analyses. These orbit/attitude combinations were chosen to meet the viewing requirements and acceleration limitations of the STO, life sciences, materials processing, and public service payloads. The radiator heat rejection capacities associated with the various attitudes are given here. A 21.5 kW heat rejection capability is required by the Orbiter and PM (12.5 kW for the powered-down orbiter and 9 kW for PM) for internally generated heat.

- Heat rejection capacity is adversely affected by absorbed solar and earthshine energy. In the orbits where the radiators are facing the sun or the earth, such as ZLV and YLV orbits, the heat rejection capacity is substantially lower.

HEAT REJECTION CAPABILITY VERSUS POINTING MODES (1 OF 2)

<table>
<tr><th rowspan="2">MODES</th><th rowspan="2">ORBIT & MISSION</th><th colspan="2">HEAT REJECTION (1)</th></tr>
<tr><th>PM</th><th>PM + ORB</th></tr>
<tr><td>XPOP, YPSL


(1)</td><td>ZSI $\beta = 0^{\circ}$
MXSI $\beta = 70^{\circ}$
MATERIAL PROCESSING LIFE SCIENCE</td><td>18.7 kW
21.4</td><td>42.5 kW
51.5</td></tr>
<tr><td>ZPOP, YPSL


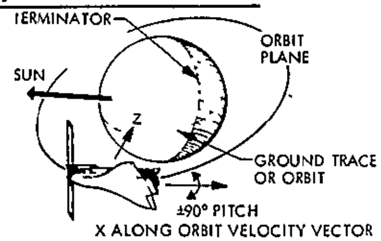
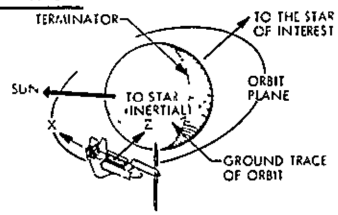
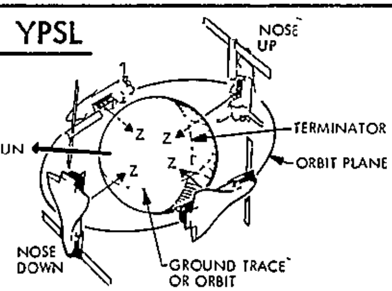
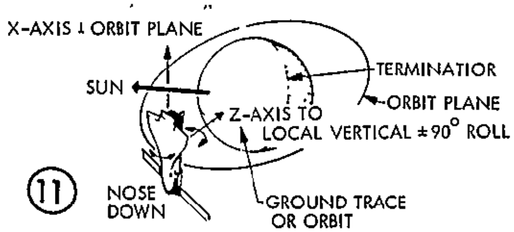
(2)</td><td>MXSI, YPOP $\beta = 0^{\circ}$
ZSI $\beta = 70^{\circ}$
MZSI $\beta = 70^{\circ}$
MATERIAL PROCESSING, LIFE SCIENCE</td><td>22.4
16.3
17.0</td><td>54.1
34.5
48.0</td></tr>
<tr><td>XIOP, ZSL ±30° PITCH


(5)</td><td>ZSI $\beta = 0^{\circ}$, 0 PITCH
ZSI $\beta = 70^{\circ}$, 0° PITCH
SOLAR OBSERVATION</td><td>18.7
17.0</td><td>42.5
48.0</td></tr>
</table>

(1) AVERAGE RADIATOR TEMPERATURE ASSUMED 50°F

These orbit/attitude combinations would be applicable to earth observation and steller inertial missions.

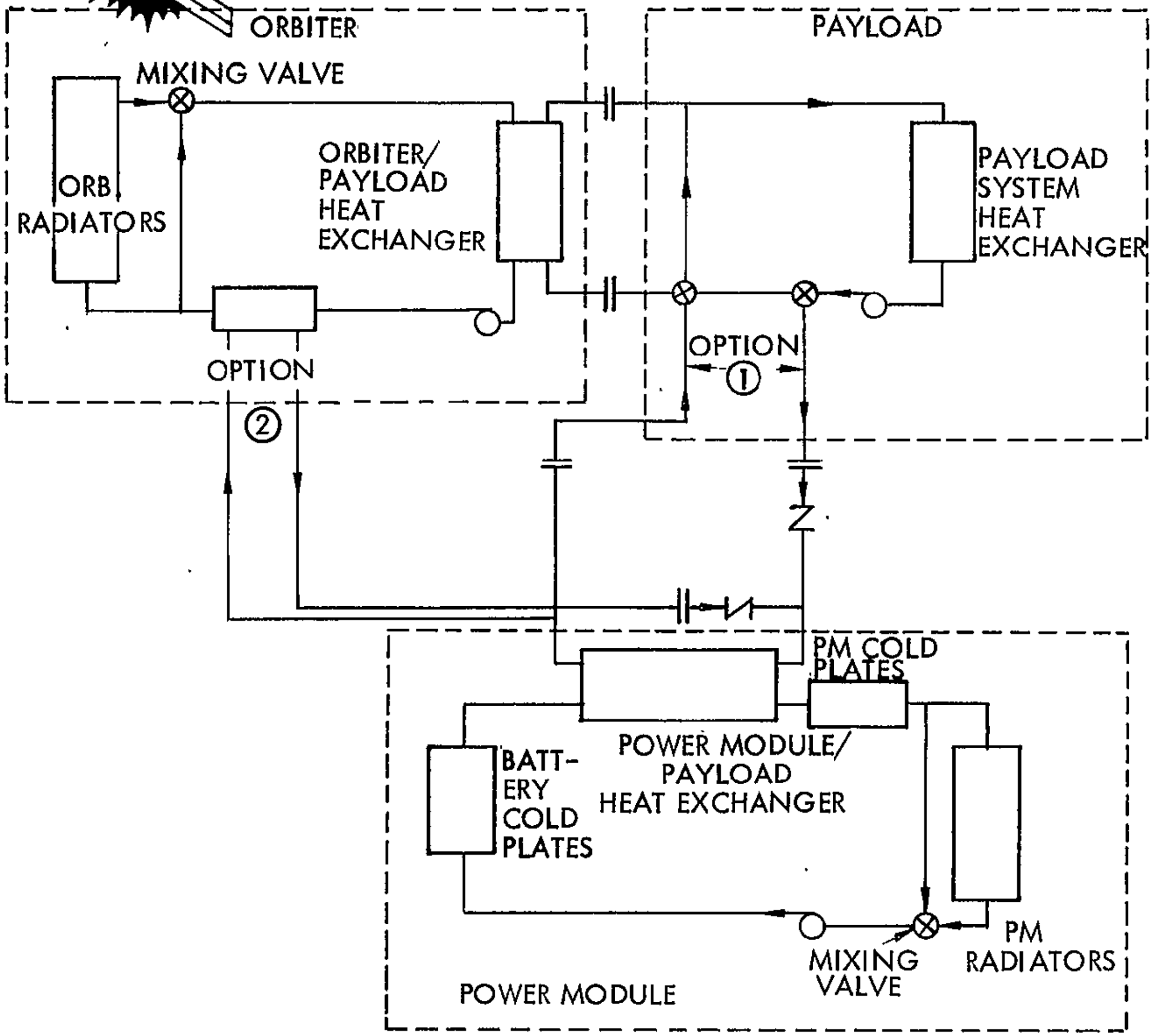
HEAT REJECTION CAPABILITY VERSUS POINTING MODES (2 OF 2)

MODES	ORBIT & MISSION	HEAT REJECTION (kW)	
		PM	PM + ORB
XVV, ZLV ±90° PITCH  (6)	ZLV, YPOP $\beta = 0^\circ$ ZLV, YPOP $\beta = 70^\circ$ EARTH OBSERVATION	20.6 kW 15.9	41.5 kW 30.9
ZSI, XIOP  (9)	ZSI, YPOP, $\beta = 0^\circ$ YLV, ZPOP (90° ROLL) $\beta = 0^\circ$ ZSI, ZPOP $\beta = 70\text{-}90^\circ$ STELLAR OBSERVATION	18.7 20.6 16.3	42.5 51.6 34.5
ZLV, YPSL  (10)	ZLV, YPOP $\beta = 0^\circ$ ZLV, YPOP $\beta = 70^\circ$ EARTH OBSERVATION (NADIR ONLY)	20.6 15.9	41.5 30.9
XPOP, ZLV ±90° ROLL  (11)	ZLV, YPOP $\beta = 0^\circ$ (0° ROLL) YLV, XPOP $\beta = 0^\circ$ (90° ROLL) ZLV, XPOP $\beta = 70\text{-}90^\circ$ (0° ROLL) YLV, XPOP $\beta = 70\text{-}90^\circ$ (90° ROLL) EARTH OBSERVATION	20.6 16.6 19.5 15.9	41.5 37.5 39.1 34.0

- Optional thermal control system interfaces between the payloads, orbiter and power module are shown. Option 1 interface transfers heat directly between the payload and the power module and can bypass or operate in series with the orbiter system. Option 2 requires that payload heat be transferred to the orbiter heat exchanger before entering the power module thermal control system.

- Flow circuit design to provide both options to payloads would provide heat rejection capabilities for all combinations of payload/orbiter/power module configurations. This would require either provisions for an orbiter TCS kit or a permanent modification of the present orbiter fluid loop.

POWER MODULE/PAYLOAD/ORBITER THERMAL CONTROL INTERFACES



OPTION ①

PAYLOAD HEAT EXCHANGE DIRECTLY WITH PM

OPTION ②

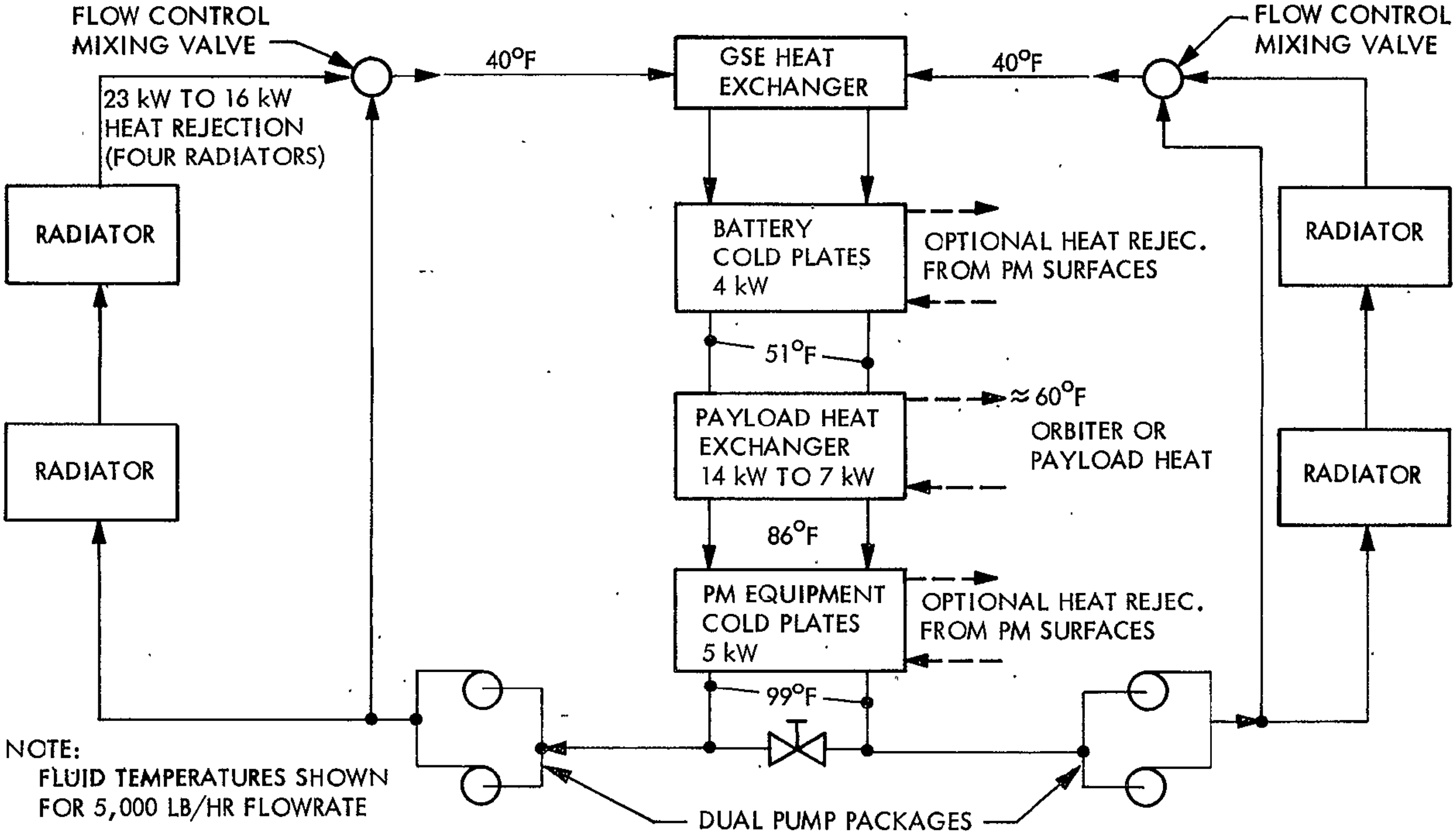
PAYLOAD HEAT REJECTION THROUGH ORBITER SYSTEM

- The thermal control subsystem in the Power Module will provide control for the batteries (50°F), the payloads, and the remaining Power Module equipment. The payload (or Orbiter) fluid loop return temperature will be approximately 60°F and is dependent on the effectiveness of the payload heat exchanger. PM equipment and power conversion component temperatures can be controlled to approximately 100°F or lower depending on the payload heat input. The baseline fluid - loop system provides flexibility and growth in battery and equipment locations.

- The parallel pump and radiator arrangement provides the redundancy required to maintain PM components within limits. The 25 kW PM will be sized for approximately 5,000 lb/hr total flow, however, the configuration shown can be upgraded to 10,000 lb/hr by selecting the existing 2,500 lb/hr Hamilton Standard pumps. Doubling the fluid loop pumping capacity and adding four additional radiator panels would essentially double the baseline PM heat rejection capability.

- The themal analysis effort included the calculation of heat rejection improvement if the Power Module battery and equipment bay exterior surfaces were utilized. Results of this analysis showed that the 4 kW dissipated in the batteries could be rejected at acceptable battery and skin temperatures. Use of these exterior surfaces would require the addition of variable conductance heat pipe loops or possibly a dedicated Freon coolant loop. A growth in payload heat rejection requirements up to a total of 23 kW could be handled by the radiators with Power Module surfaces designed to handle internal equipment temperature control.

POWER MODULE THERMAL CONTROL SYSTEM



NOTE:
FLUID TEMPERATURES SHOWN FOR 5,000 LB/HR FLOWRATE

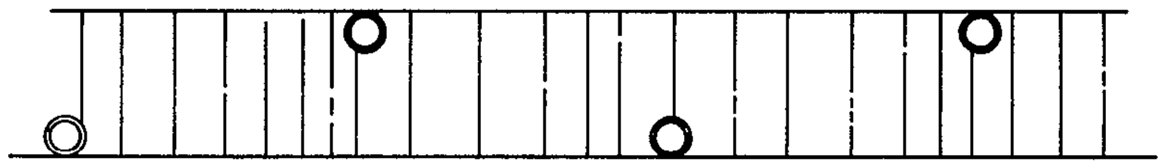
- The following two charts describe the meteoroid protection analysis, protection requirement and weight comparisons for heat pipe and liquid flow radiators. Catastrophic failure of a radiator is assumed to have occurred when a Freon-21 filled tube is ruptured with a resultant loss of liquid. Conversely, rupture of a heat pipe was treated as a slight degradation in heat rejection performance and not a failure. The analysis was based on the expected meteoroid penetration data and calculations published by R. J. Naumann in 1966, and correllations developed for double plate structures by C. R. Nysmith in 1969.

- The simplest fluid tube protection is provided by bonding a flat cover to the exposed radiator surface to shield the tube, or the liquid manifold in a heat pipe radiator design. This concept would be the easiest to fabricate and could be retrofitted to existing radiator panels.

- Alternate protection concepts are being analyzed by LMSC and others such as Vought Corp (orbiter radiator suppliers). These alternatives and the theoretical weight savings potential are shown on the following chart. Optimized designs, development of fabrication techniques, and evaluation of the overall radiator performance capabilities will require additional effort.

METEOROID PROTECTION WEIGHT OF HEAT PIPE VS FLUID FLOW RADIATORS

BASELINE: FLAT 4.6m x 3. 1m (15 FT x 10 FT) RADIATOR
WEIGHT WITHOUT HARDWARE = 5.62 KG/M^2 = 1.15 PSF



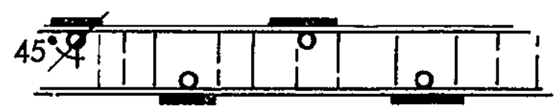
BASIS OF COMPARISON: SINGLE-WALL METEOROID SHIELDING PLATES APPLIED AS SHOWN.

PENETRATION FREQUENCY AS PER NASA TN-D-3717 "THE NEAR EARTH METEOROID ENVIRONMENT," R. J. NAUMANN, 1966

FLUID-FLOW AND HEAT PIPE RADIATORS DESIGNED FOR EQUAL THERMAL PERFORMANCE

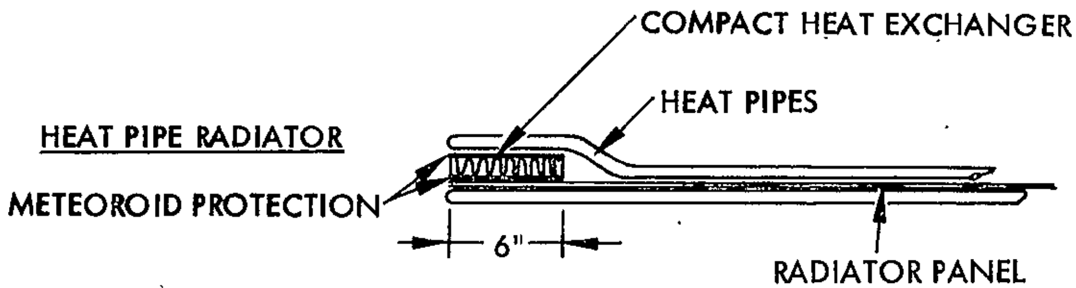
ASSUMED PROTECTION SCHEMES:

LIQUID FLOW RADIATOR



EACH TUBE PROTECTED

HEAT PIPE RADIATOR



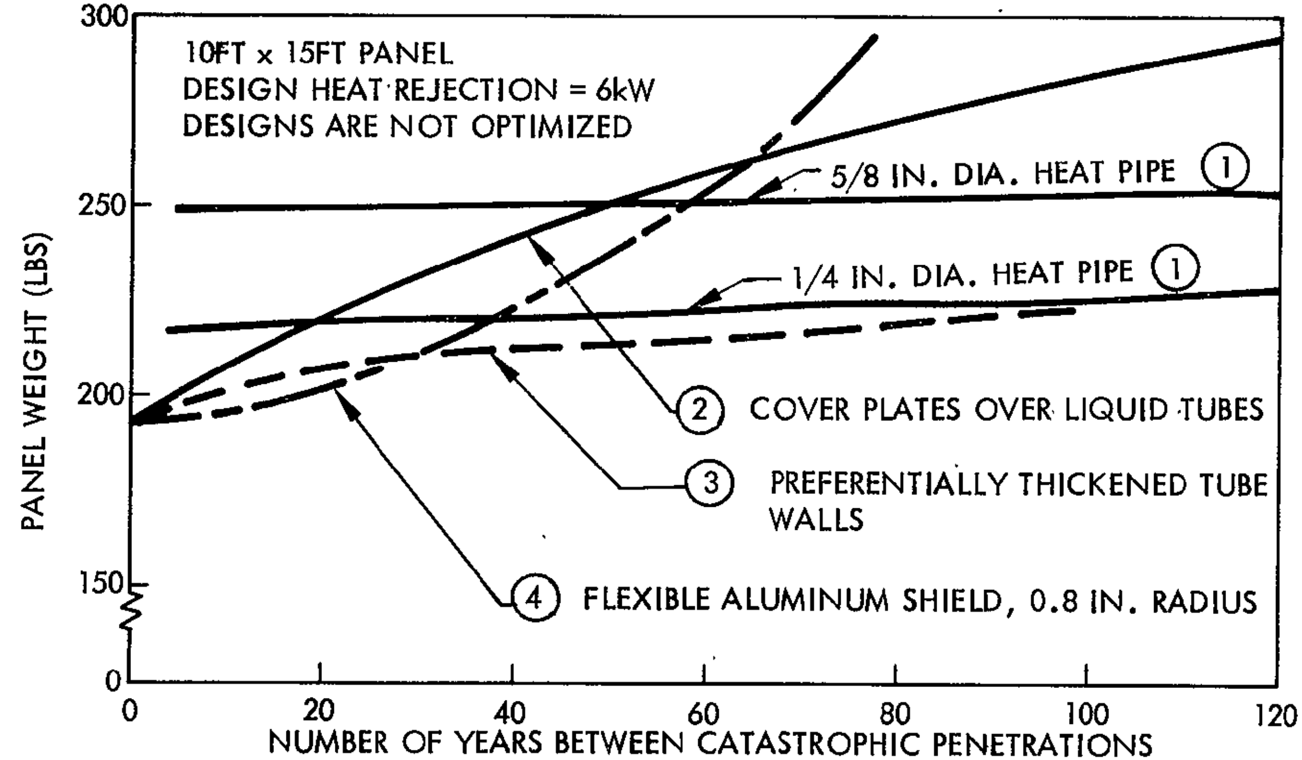
HEAT DISTRIBUTION DUCT PROTECTED ONLY

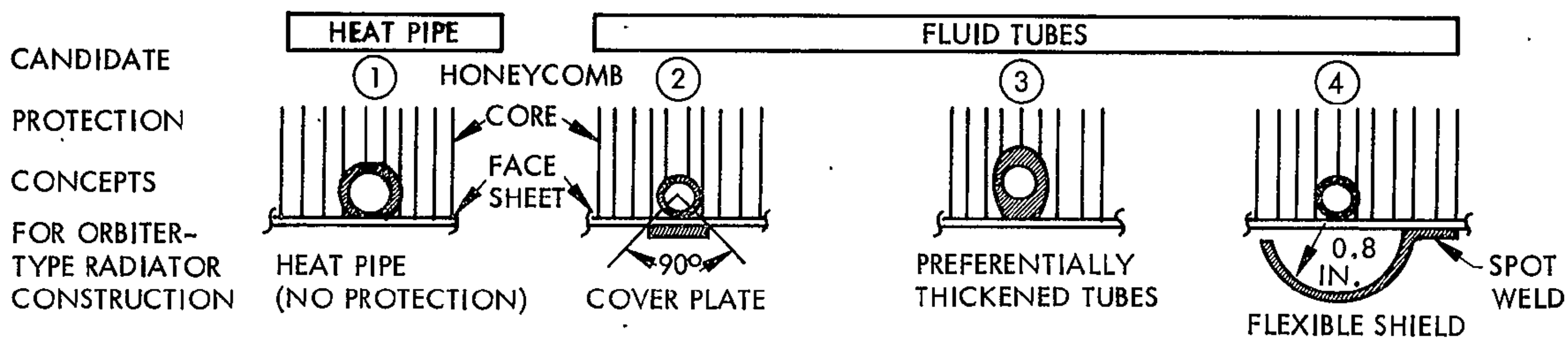
- This chart presents the potential radiator panel weights for heat pipe radiators with Freon-21 liquid manifolds and all liquid-flow panels similar to the existing Orbiter design. Redundant fluid passageways were not included in the analytical model of the radiator panels.

- With no protection requirement, the heat pipe radiators are heavier than the fluid-flow panels sized for equal heat rejection. This weight penalty (for no meteoroid protection) can be reduced by designing an efficient heat exchanger for the Freon-21 manifold-to-heat pipe interface and by optimizing tube design and spacing.

- Analysis of radiator weights for three liquid filled radiator panels was completed for configurations 2 , 3 , and 4 shown on the chart. Protection of the fluid tubes by increasing the metal thickness through which the meteoroid must travel is shown in configurations 2 and 3 . Protection based on an "energy-diffusing" standoff bumper is shown as configuration 4 . The flexible shield concept allows the shield to be depressed when the radiators are stowed. Effectiveness of the bumper is directly proportional to thickness and standoff distance. This protection effectiveness must be traded against decreasing flexibility and overall radiator performance which is illustrated by the increasing slope of the weight curve for configuration 4 .

COMPARATIVE WEIGHTS OF METEOROID PROTECTION



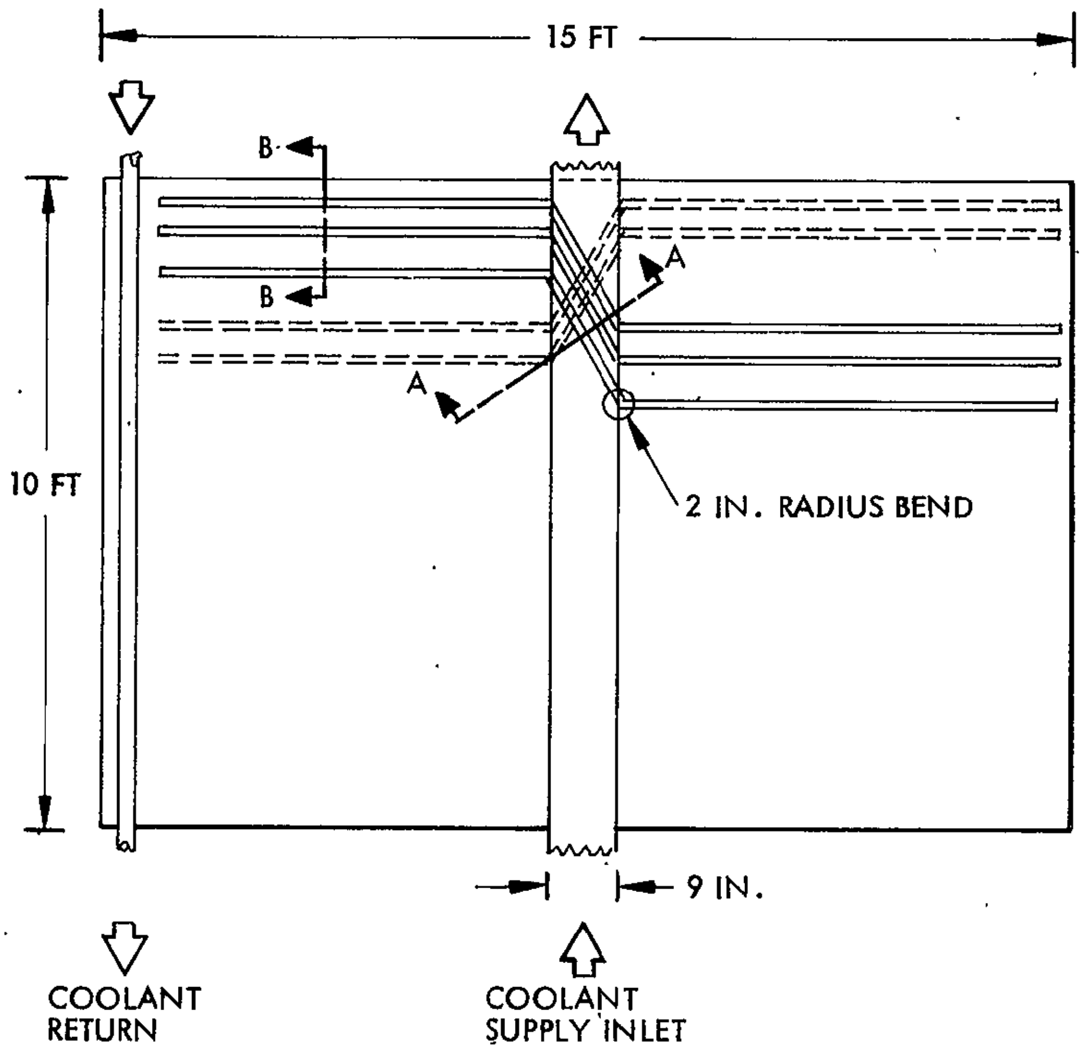


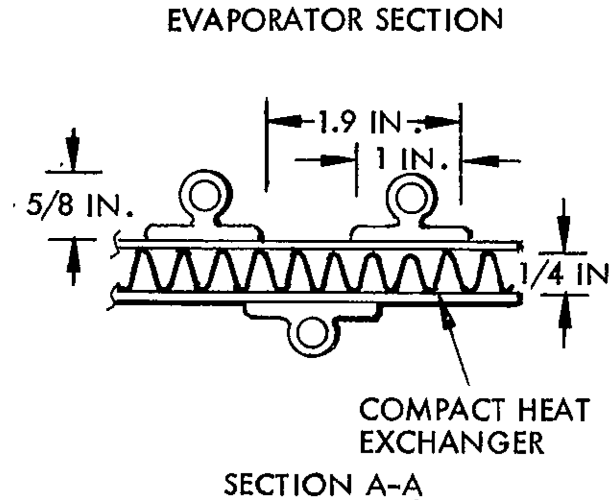
- The thermal transport capability of a 1/2 inch O. D. axial groove heat pipe using ammonia as the working fluid is approximately 4000 watt-inches. The heat pipe arrangement shown for a 10 ft by 15 ft radiator panel will handle a 6 kW heat load. Expected development of arterial heat pipes with twice the transport capability may simplify the radiator design.

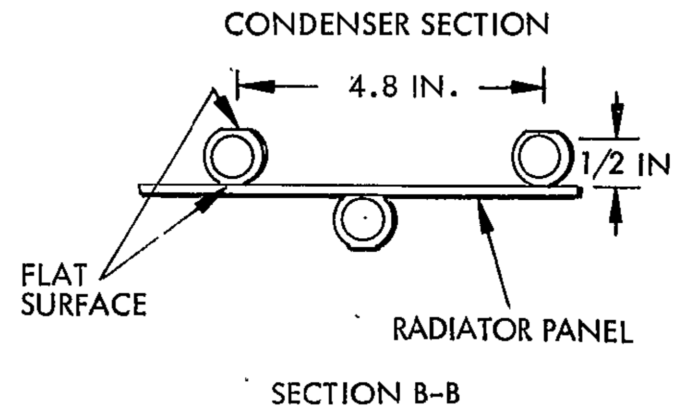
- The heat pipe radiator requires a compact heat exchanger to conduct heat from the fluid loop to the heat pipe evaporator section. Good heat transfer at this interface is critical to radiator performance.

- The heat pipe is flattened at the bottom, as shown in the cross-section view, to enhance the thermal contact between the heat pipes and the radiator panel. A fabrication simplication of flat surfaces on two sides of the heat pipe is shown.

HEAT PIPE RADIATOR DESIGN CONCEPTS







- Initial Power Module concepts have included the use of the orbiter fluid loop radiators which are curved to conform to the cargo bay doors. Although the curved radiator is an existing design, analysis has shown that a flat radiator has major advantages when considered for use on the Power Module.

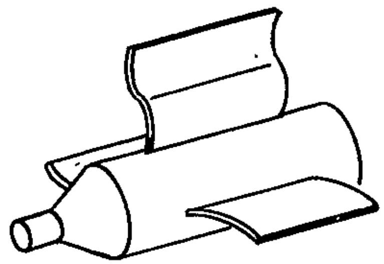
- Analysis results shows that the heat rejection capability of a flat radiator is up to 13 percent more than a curved radiator of equal area. The reduced "view" of space for the concave surfaces contribute to this significant reduction. Growth of the curved system is limited to one panel per side due to storage limitations.

- Performance and comparative advantages and disadvantages are listed in the accompanying chart. An average radiator temperature of 50°F was assumed in the performance comparison.

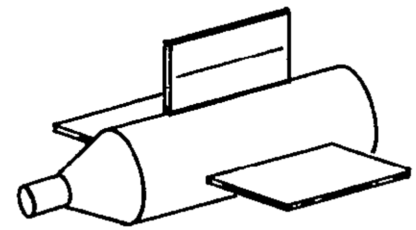
- The results of this analysis clearly show major advantages for flat radiator panels. Therefore, flat radiators are recommended as the prime configuration for subsequent analysis, design, and costing exercises.

COMPARISON OF CURVED VS FLAT RADIATORS

CURVED RADIATOR SYSTEM



FLAT RADIATOR SYSTEM



ADVANTAGES:

Curved radiator system:

- EXISTING DESIGN
- AVAILABLE GROUND TEST PERFORMANCE DATA

Flat radiator system:

- GREATER THERMAL EFFICIENCY
- PREFERABLE FOR HEAT PIPE RADIATOR DESIGN
- CUSTOMIZED DESIGN
- TOOLING & TEST FIXTURE SIMPLICITY
- BETTER "ADD ON" GROWTH CAPABILITY
- FIRST VEHICLE COSTS ARE 5.7% LESS

DISADVANTAGES:

Curved radiator system:

- INEFFICIENT USE OF STOWAGE VOLUME
- 4% TO 10% INCREASED WEIGHT

Flat radiator system:

- NEW DESIGN
- QUAL COSTS

RADIATOR SYSTEM PERFORMANCE

TOTAL HEAT REJECTION CAPABILITY			
SAMPLE ORBIT	CURVED RADIATOR	FLAT RADIATOR	%Δ
MXSI BETA 0°	22.4 kW	25.2 kW	10%
YLV BETA 70°	15.7 kW	17.7 kW	13%

- Silver-backed teflon film (FOSR) is used on the Orbiter radiator panels and the optical properties of FOSR have been included in the thermal analyses. This material has exhibited a durability to handling and cleaning which simplifies the maintenance of long-life radiator panels.

- The cost for painted surfaces depends in part on the thickness of the layer required. Thicker layers (of 10 to 20 mils) require more coating and raises the cost. When handling and cleaning procedures are included, the cost for paint increases faster than that of FOSR.

- The surfaces must be prepared and primed before paint can be sprayed on. In the FOSR application, it is important to eliminate blister and bubbles to assure proper bonding.

PAINT VS FEP TEFLON FOSR [1]

PARAMETER	WHITE ZINC ORTHOTITANATE SILICONE PAINT	S-13 GLO WHITE SILICONE PAINT	SILVERIZED FEP - TEFLON FOSR	ALUMINIZED FEP - TEFLON FOSR
α/ϵ INITIAL	0.20/0.86	0.24/0.88	0.07/0.80	0.12/0.80
α/ϵ AFTER 5 YEARS	0.40/0.86	0.50/0.88	0.20/0.80	0.25/0.80
APPLICABILITY	DIFFICULT	DIFFICULT	DIFFICULT	DIFFICULT
CLEANABILITY	DIFFICULT	DIFFICULT	EASY	EASY
COST PER SQ FT	$25 OR MORE	$25	$150	$150
PREVIOUS EXPERIENCE	NONE (TBD)	EXTENSIVE (LOCKHEED)	EXTENSIVE (LOCKHEED & OTHERS)	EXTENSIVE (LOCKHEED & OTHERS)

Note: (1) FEP-Teflon FOSR is a metallized (Aluminum or Silver) Teflon sheet that provides a flexible optical solar reflector (FOSR).

- Based on the average value of 30 W/ft^2, the larger Power Module Concepts (100 kW and 200 kW concepts) would have 20.0 kW heat rejection capacity for the payload in the 100 kW configuration and no payload heat rejection capability for the 200 kW module.

- If the payload is to provide its own heat rejection capability in the 100 kW module configuration, the radiator area would be reduced to 670 ft^2.

- The expected radiator panel technology improvements will result in a higher heat rejection capability per pound of radiator for the 100 kW and 200 kW Power Module. For example: As the design heat rejection increases by a factor of 2.17, comparing the 25 kW to the 200 kW PM, the radiator weight is expected to increase by a factor of 1.53.

POWER MODULE THERMAL SUBSYSTEM GROWTH CHARACTERISTICS

AVERAGE POWER (kW)			THERMAL RADIATOR PANELS[1]				PANEL TECHNOLOGY (RADIATE 30W/FT^2)[2]		
ELECTRICAL OUTPUT	RADIATOR CAPACITY		NO.	SIZE (FT)	TOTAL AREA	WEIGHT (LB)	YEAR	PANEL CONFIGURATION	LB/FT^2
	FOR PM	FOR P/L							
25	9	9.9	4	10.5 X 15	630	882	1978	CURVED/ HONEYCOMB	1.4
50	18	22.5	12	7.5 X 15	1350	1890	1978	FLAT	1.4
100	20.5	20	12	7.5 X 15	1350	1620	1986	FLAT/ADV DESIGN	1.2
200	41	0	12	7.5 X 15	1350	1350	1990	FLAT/ADV DESIGN	1.0

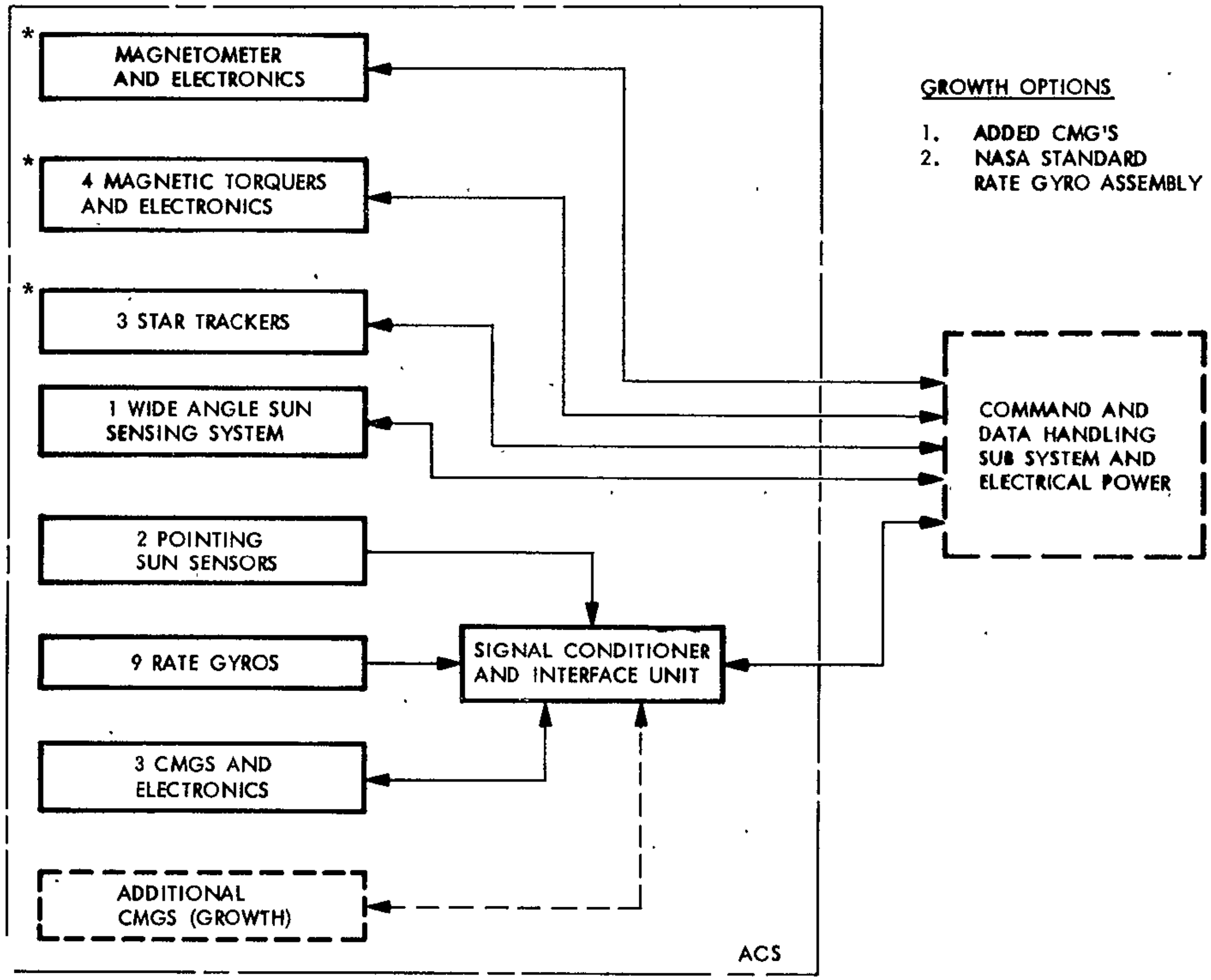
(1) REFERENCE AREA IS PANEL AREA (ONE SIDE).

(2) RADIATOR CAPABILITY RANGES FROM 25 TO 35W/FT^2, BASED ON AN AVERAGE RADIATOR TEMPERATURE OF 50°F. THIS NOMINAL CAPABILITY IS BASED ON THE TOTAL RADIATING AREA OF THE PANELS (BOTH SIDES).

PM ATTITUDE CONTROL GROWTH

Growth of the PM ACS is required to meet increased payload requirements, such as mass properties, cluster configuration, pointing accuracy, slewing, and desired orbital attitude, but not necessarily power level. In order to minimize risk and development costs, maximum use of proven technology will be employed. NASA standard components will be utilized when new components are required. Changes to the baseline 25 kW Power Module that will facilitate the incoration of growth are identified and will be further examined in Part III.

ATTITUDE CONTROL SYSTEM



*RECOMMENDED CHANGES TO BASELINE

Because the available ATM rate gyro packages are planned for the first 25 kW Power Module, subsequent requirements must be satisfied by alternative sensors. The prime candidate is the NASA Standard High Performance Inertial Reference Unit (DRIRU-II). The satisfaction of mission requirements with a less expensive sensor, or mission requirements that exceed the performance of the standard could lead to the choice of another sensor. The performance specification for the inertial reference units that are currently flying on the HEAO and IUE programs are shown to demonstrate the general availability of this type of sensor.

ACS GROWTH - SENSORS

CANDIDATE GYRO PACKAGE PERFORMANCE SPECIFICATIONS

PARAMETER	DRY INERTIAL REFERENCE UNIT (DRIRU-2)	HIGH ENERGY ASTRONOMICAL OBSERVATORY (HEAO)	INTERNATIONAL ULTRASONIC EXPOSURE (IUE)
• BANDWIDTH (Hz)	7	>10	>5
• NOISE (Hz/s/s RMS)	1 s NEA 1 HOUR 5 SPS	0.5 s RMS (32 ARC MIN 0.32s SAMPLES) 1.0s MAX (ANY 3 SAMPLES)	2 s MAX DEVIATION 35 ARC MIN 10 SPS
• SCALE FACTOR			
QUANTIZATION (s PER PULSE; HI/LO MODE)	0.05/0.8	0.1/NA	0.01/0.3
KNOWLEDGE (PPM)	50	NS	NS
STABILITY (PPM/MO)	-100 LO MODE; 1000 HI MODE	75 (2 DAY)	100
LINEARITY (PPM LO MODE/HI MODE)	100/NA	100 TO ±1°/5; 1000 ± 1 TO ± 2.5	1000
ASYMMETRY	50/NA	INCLUDED	INCLUDED
• ALIGNMENT (s)			
KNOWLEDGE	±5	NS	NS
STABILITY	±10	±20	±15
• G-INS DRIFT			
STABILITY	0.04°/HR LO MODE 3.6°/HR HI MODE (30 DAYS)	0.002°/HR/HR (12 HR)	±0.01°/HR (35 DAY)
• ANALOG RATE			
KNOWLEDGE (PPM)	±1.0°/s	±2.5°/SEC	±5°/s
LINEARITY (PPM)	NA 10^5	NS NS	NS NS
• RATE RANGE			
LOW MODE	±400 s/s	±2.5°/s	±500 s/s
HI MODE	±1.6°/s	NA	±4.2°/s

NA – NOT APPLICABLE, NS – NOT SPECIFIED

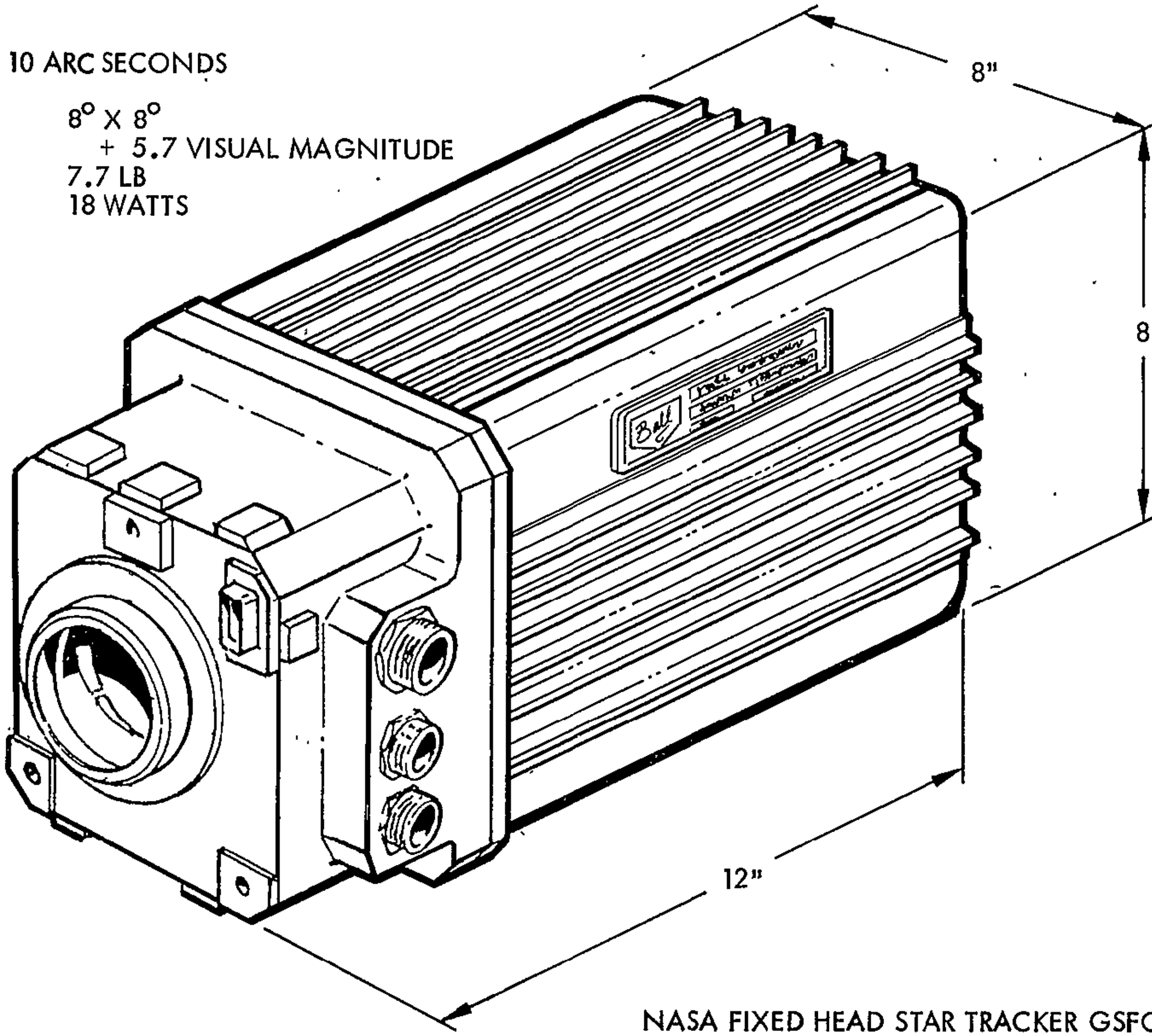
NEA = NOISE EQUIV ANGLE SPS = SAMPLES PER SECOND

If a pointing accuracy requirement is imposed on the Power Module, a pointing sensor will be added. The prime candidate to meet this requirement is the NASA Standard Fixed Head Star Tracker. This device is currently used on Orbiter, and is baselined for Space Telescope.

ACS CANDIDATE STAR TRACKER

ACCURACY TO 10 ARC SECONDS

FIELD OF VIEW	$8^\circ \times 8^\circ$
TARGET STAR	+ 5.7 VISUAL MAGNITUDE
WEIGHT	7.7 LB
POWER	18 WATTS

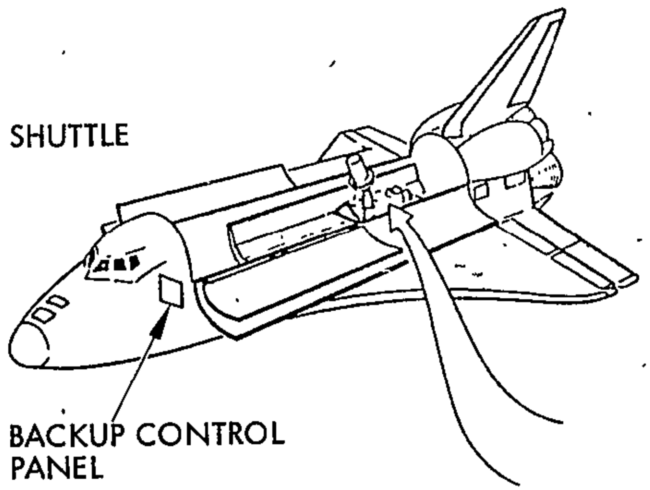


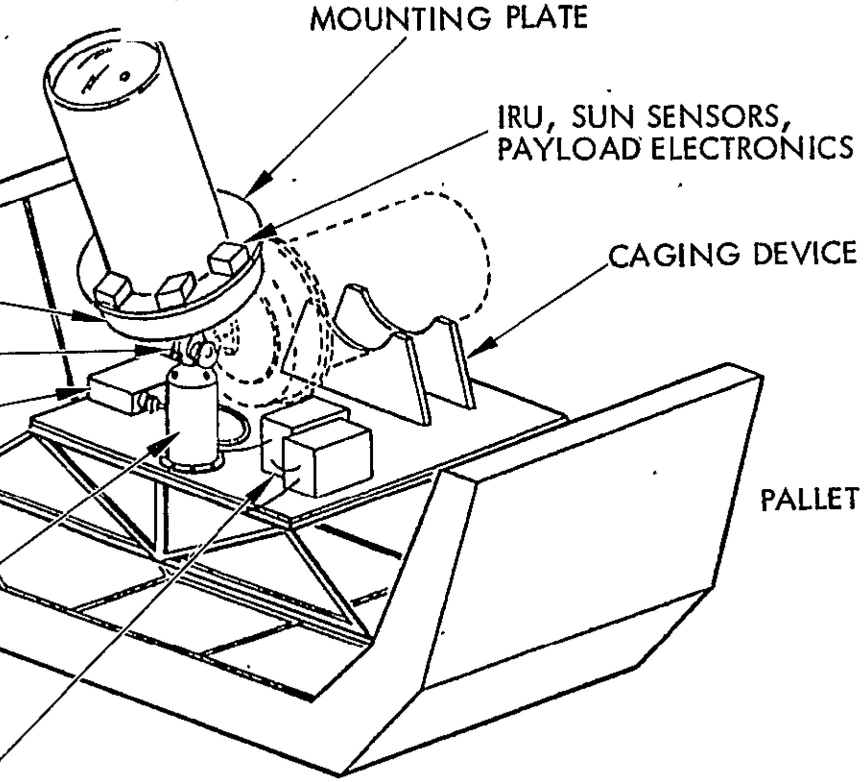
NASA FIXED HEAD STAR TRACKER GSFC-S-712-9

When payload pointing requirements are such that the Power Module ACS cannot meet the requirements, an experiment pointing mount can be utilized. The Annular Suspension Pointing System is an example of an experiment pointing mount that is capable of providing ±0.1 arc second pointing accuracy to payloads up to 600 kg mass. Magnetic actuators are used in this system to provide a fully levitated payload mounting base isolated from Orbiter disturbances. An engineering model of this pointing system is scheduled to undergo performance testing beginning in mid-78. Other candidate experiment pointing mounts are the Instrument Pointing System, Small Instrument Pointing Systems, Modified ATM Star Tracker, and Gimbalflex.

ACS AUGMENTATION – ANNULAR SUSPENSION POINTING SYSTEM

POINTING ACCURACY	±0.1 ARC SECOND
POINTING STABILITY	±0.01 ARC SECOND
WEIGHT	823 POUNDS
AVERAGE/POWER	89 WATTS
PEAK POWER	1100 WATTS, MAXIMUM
PAYLOAD WEIGHT	600 KILOGRAMS, MAXIMUM

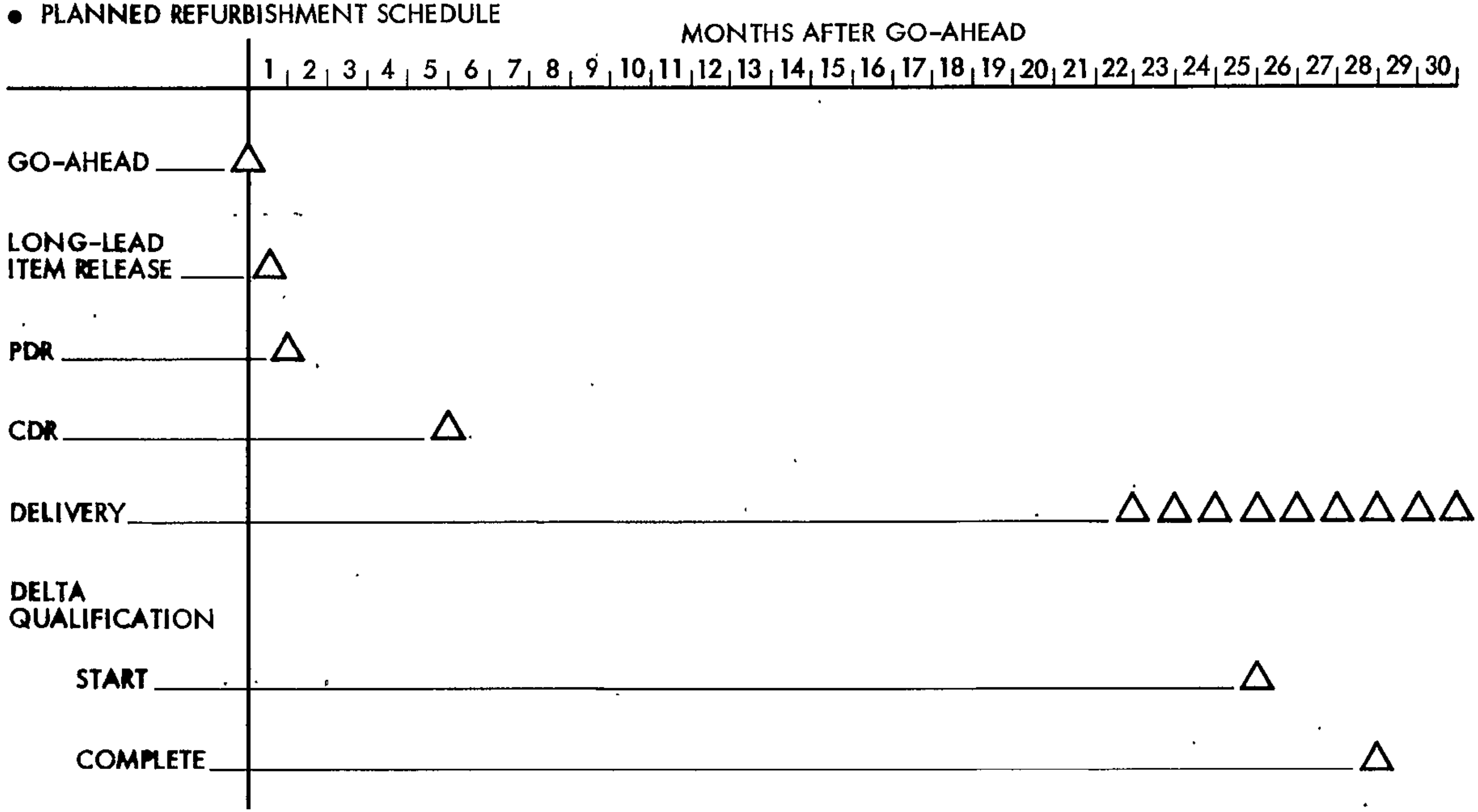




A planned refurbishment schedule for the existing nine ATM CMGs is shown. The plan which provides for the delivery of one CMG per month starting in the 22nd month, is completed in 30 months (including delta qualification). If this plan is initiated in mid CY '79, nine CMGs will be available at the end of CY '81.

ACS GROWTH — CMG'S

- PLANNED REFURBISHMENT SCHEDULE



- ADDITIONAL CMGs AVAILABLE ON THE SAME SCHEDULE – 22 MONTHS FROM START TO DELIVERY OF FIRST UNIT DELIVERY OF ONE PER MONTH
- FIRST 3 CMGs REQUIRED 12 MONTHS, MINIMUM, PRIOR TO FIRST FLIGHT OF POWER MODULE

There is no requirement for the power module to provide a desaturation system in the sortie mode as the Orbiter will provide this capability. In the free-flying mode, however, some provision to unload the CMGs is required. This requirement becomes more severe if attitudes other than principal axis along the local vertical or perpendicular to the orbit plane are used to meet payload pointing requirements. In addition, when the PM vehicle utilizes a manned habitat, a redundant ACS actuation system is required.

ACS MOMENTUM DESATURATION REQUIREMENTS

SORTIE MISSIONS

- DESATURATION PROVIDED BY ORBITER RCS

FREE FLYING MISSIONS

- REQUIRED ON ALL ATTITUDES WHICH DEVIATE FROM LOCAL VERTICAL – ORBITAL PLANE PRINCIPAL COORDINATE SYSTEM ORIENTATIONS (STO, STELLAR POINTING)

- A REDUNDANT ACTIVATION SYSTEM IS REQUIRED WHEN A MANNED HABITAT IS ATTACHED TO PM

Four candidate momentum desaturation schemes were evaluated for a number of parameters, as shown in this chart. The first three, reaction jets, electromagnets, and ion thrusters, require additional hardware but no maneuvering. The use of gravity gradient torques require maneuvering, but no hardware.

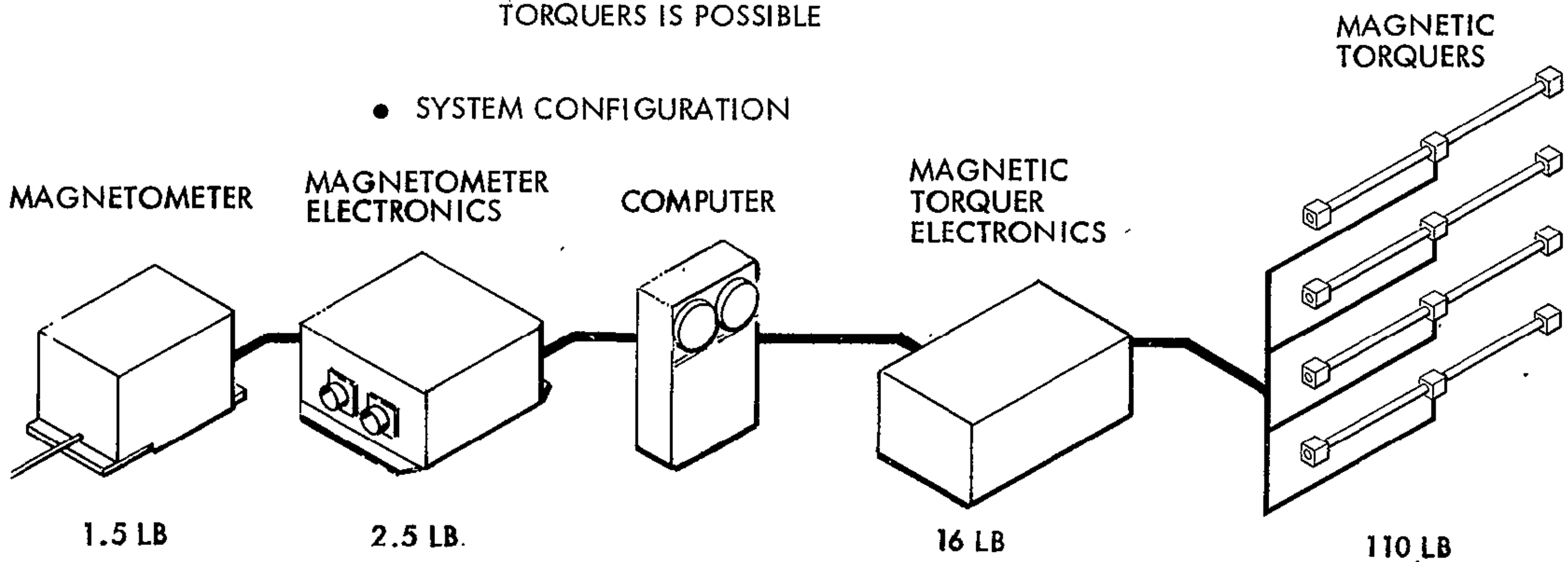
ACS MOMENTUM DESATURATION CANDIDATES

CANDIDATE CONCEPT / CHARACTERISTICS	REACTION JETS	MAGNETIC TORQUERS	ION THRUSTERS	GG MANEUVERING
MANEUVERING REQUIRED	NONE	NONE	NONE	YES
SURFACE CONTAMINATION	POSSIBLE	NO	NEGLIGIBLE	NO
COMPUTATION REQUIRED	SMALL	LARGE	SMALL	LARGE
DESATURATION TIME	SHORT	MODERATE	LARGE	LARGE
EXCITATION OF FLEX MODES	YES	NEGLIGIBLE	NEGLIGIBLE	SMALL
NUMBER OF AXES FOR SIMULTANEOUS DESATURATION	3	2	3	3
RECOVERY FROM SATURATED CONDITION	EXCELLENT	GOOD	POOR	NONE
MISSION TIME LOSS	SMALL	NONE	NONE	LARGE

One implementation of a magnetic torquing system is the use of hardware currently being designed for the Space Telescope program, as shown in this chart. In addition to making qualified hardware available to the Power Module, this implementation permits the software (control laws) being developed for Space Telescope to be applied to the Power Module. Future payloads with larger inertias can be accommodated by the addition of magnetic torque rods.

ACS RECOMMENDED DESATURATION SYSTEM IMPLEMENTATION

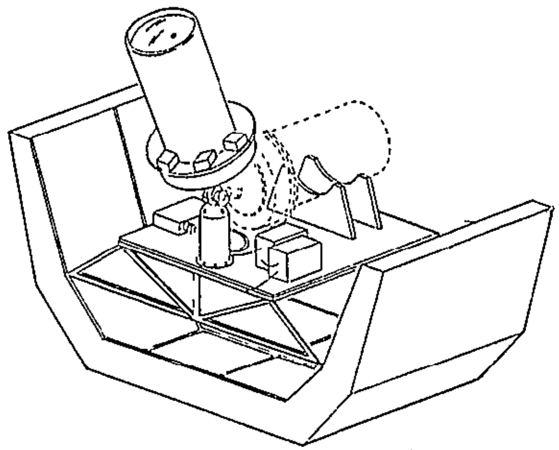
- USE SPACE TELESCOPE HARDWARE (MAGNETS) AND ALSO ADJUST SOFTWARE (CONTROLLERS)
  - 4 MAGNETS TO MEET EARLY MISSION REQUIREMENTS
  - MODULAR GROWTH BY ADDITION OF TORQUERS IS POSSIBLE
- SYSTEM CONFIGURATION



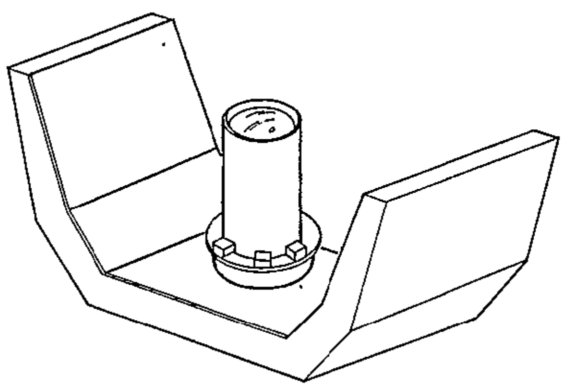
- When the Power Module is flying in the sortie mode with the Orbiter, several options are available for payload pointing. In the baseline 25 kW configuration, the prime option is Power Module pointing, if a pointing sensor is available. Alternatively, the Orbiter or an experiment pointing mount can provide the pointing required. A more complex option involves utilizing both the Orbiter and Power Module for pointing.

- In the free-flying mode, the Power Module can provide the payload pointing (if a pointing sensor is available). When pointing requirements exceed the Power Module capabilities, an experiment pointing mount is required.

ACS POWER MODULE PAYLOAD POINTING OPTIONS



SENSOR MOUNTED
ON POINTING PLATFORM



SENSOR HARDMOUNTED
TO PALLET

POINTING OPTIONS

ORBITER SORTIÉ WITH POWER MODULE

MODE I ORBITER POINTING
MODE II POWER MODULE POINTING
MODE III POINTING PLATFORM
MODE IV ORBITER/POWER MODULE POINTING

FREE-FLYING POWER MODULE

MODE II POWER MODULE POINTING
MODE III POINTING PLATFORM

Growth of the ACS to support Power Module growth configuations will be studied in Part III of this study. The parallel mounted CMG control law makes modular growth of the momentum exchange system feasible when the momentum sizing analysis shows a requirement. The capability of the rate gyros to meet future requirements will be studied, as well as the requirement for a position sensor. As the Power Module grows, supporting various configurations of spacecraft flexibly coupled together, the vehicle control law will require modification and may need to be made compatible with various payload sensors. The requirement for desaturation will be analyzed in parallel with the momentum exchange system growth.

PM ATTITUDE CONTROL GROWTH PHILOSOPHY

- GROWTH IS SENSITIVE TO PAYLOAD REQUIREMENTS, NOT POWER LEVEL
- MAXIMIZE USE OF PROVEN, LOW RISK HARDWARE
- USE NASA STANDARD COMPONENTS TO MEET NEW REQUIREMENTS

PM ATTITUDE CONTROL
CONCLUSIONS AND RECOMMENDATIONS

- ADD ATM CMGs TO MEET INCREASED MOMENTUM STORAGE REQUIREMENTS
- ADD HORIZON SENSOR TO MEET COURSE POINTING REQUIREMENTS FOR FREE-FLYER
- ADD THREE STAR TRACKERS TO MEET FINE-POINTING REQUIREMENTS FOR FREE-FLYER
- SELECT TYPE AND SIZE OF MOMENTUM DESATURATION SYSTEM THAT MEETS PAYLOAD REQUIREMENTS FOR FREE-FLYER
- USE NASA STANDARD RATE GYRO ASSEMBLY FOR ADDITIONAL POWER MODULES

C&DH SUBSYSTEM GROWTH ANALYSIS

This chart summarizes the key drivers that result in the selection of a C&DH System.

C & DH GROWTH DRIVERS

- THE MSFC BASELINE 4 KBPS POWER MODULE DESIGN DOES NOT ALLOW PAYLOAD DATA PROCESSING OR TELEMETRY AND COMMAND GROWTH CAPABILITY OF THE POWER MODULE.

- THE BASELINE MMS STANDARD TELEMETRY AND COMMAND COMPONENTS (STACC) TELEMETRY CAPABILITY IS 64 KBPS AND REQUIRES THE RF SYSTEM SHOWN ON PAGE 2F-113.

- TELEMETRY DATA RATES ESTIMATED REQUIREMENTS FROM PART 1 ARE 15-35 MBPS AND 24 MHz ANALOG (VIDEO) FOR SOLAR/TERRESTRIAL MISSIONS IN THE 1983 TO 1990 TIME FRAME.

- This chart shows the basic RF system required for telemetry bit rates from MSFC baseline rate of 4 kbs to a maximum bit rate of 1 mbs (TDRSS multiple access 50 lb, single access to 1 mbs).

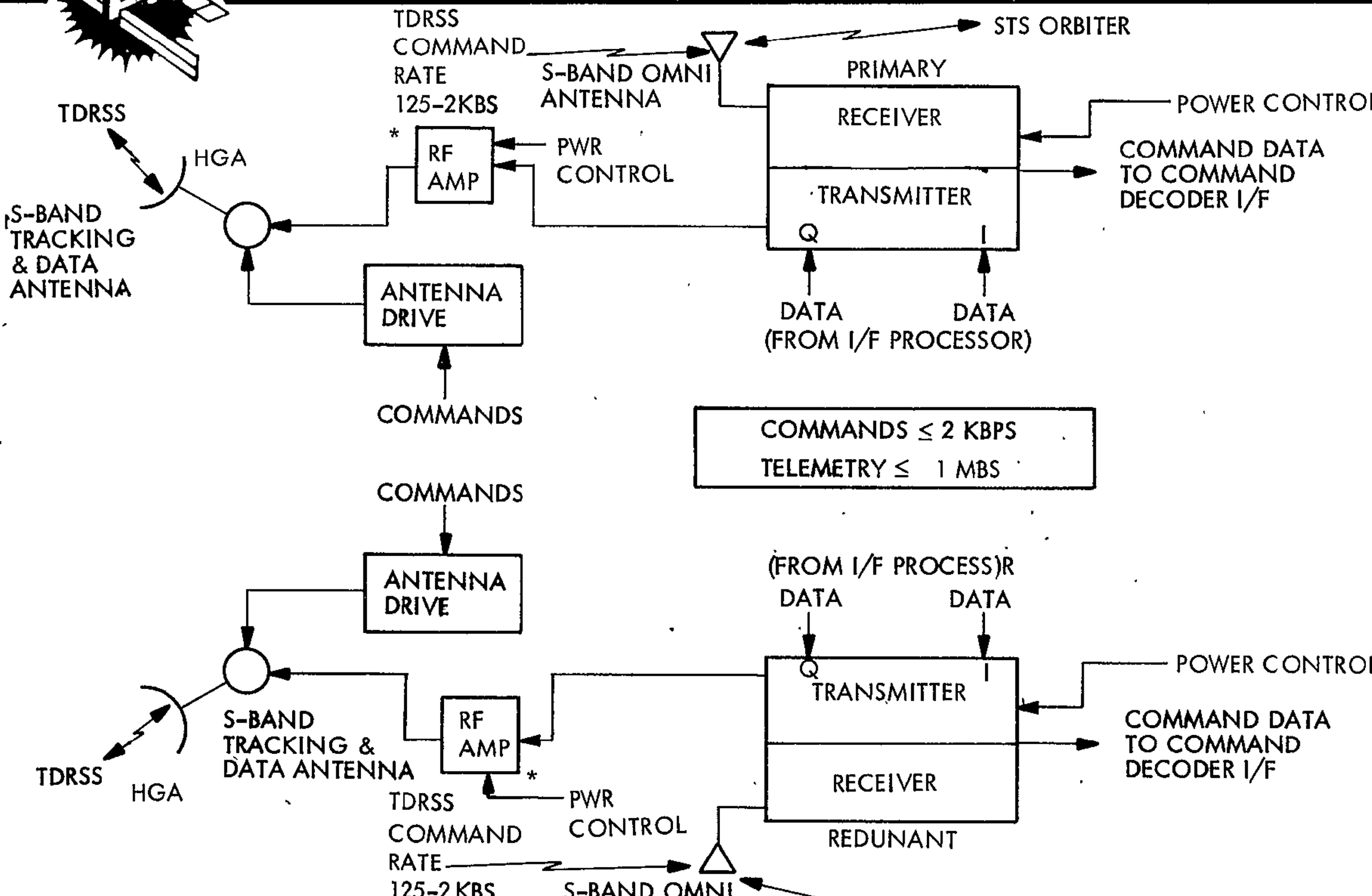
- An RF amplifier of 14 watts minimum is required for bit rates from 256 kbs to 1 mbs.

- The high-gain parabolic antenna is envisioned to be a modified space telescope antenna with a nominal gain of 21.8 dB at S band (gain at Ku band TBD).

- Transponders are 5 watt NASA standard TDRSS/STDN units with diplexers.

- The telemetry system for data rates above 1 mbs is shown on Page 2F-121.

C & DH COMMUNICATIONS SYSTEM
GROWTH SYSTEM CONCEPT



* REQUIRED FOR
BIT RATES 256KBS TO 1 MBS

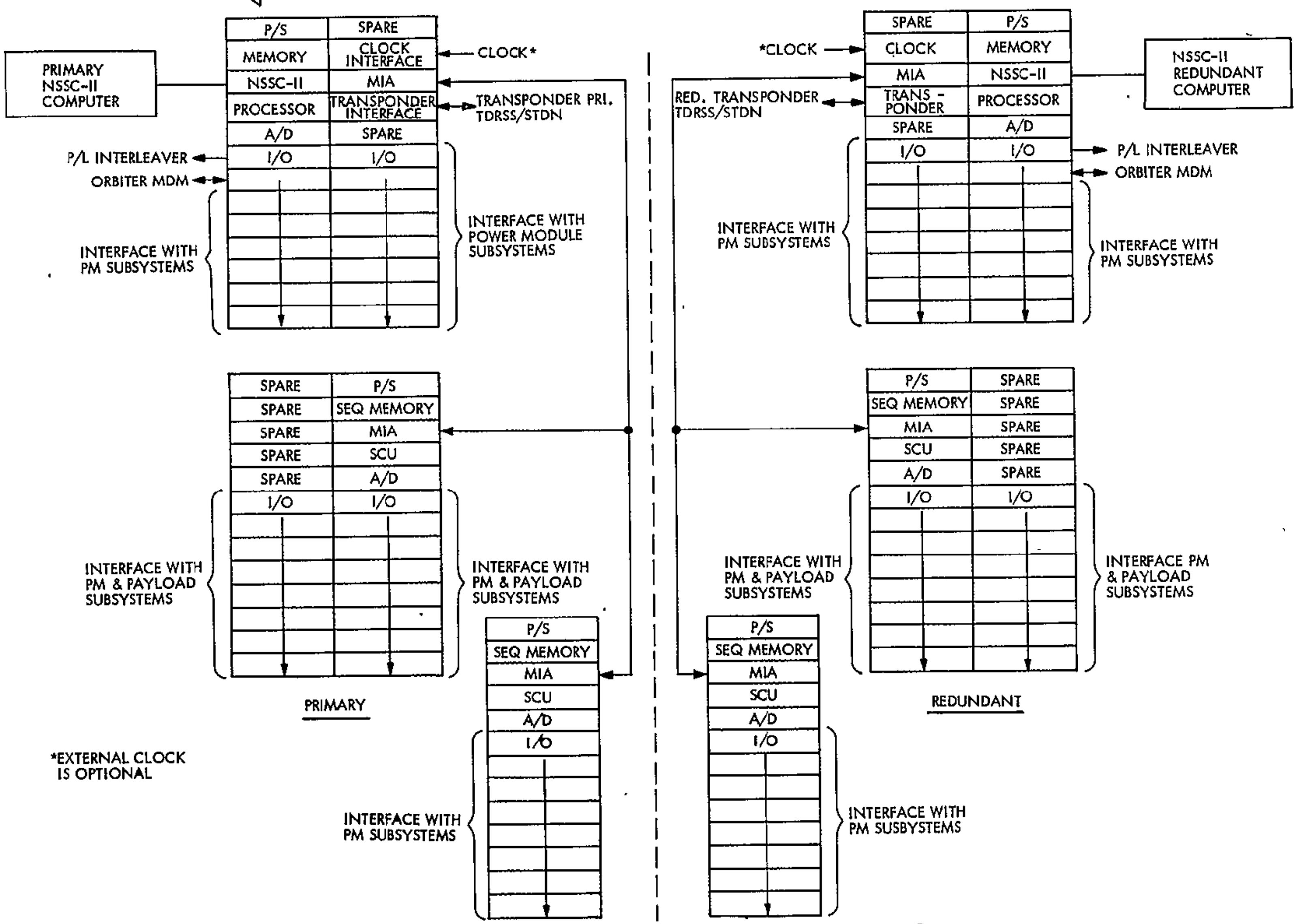
- This chart is a system for data management and control of the Power Module and associated payloads. The system is based on a central microprocessor to perform routine housekeeping functions. Input/output cards provide interface with the Orbiter, PM, and payloads. Telemetry, command, and timing cards are provided. Telemetry and command formats can be preprogrammed or changed in-flight by the on-board computer (NSSC-II).

- Bit rate growth from the MMS 64 kbs to a bit rate of 256 kbs is provided.

- The system is a database design and growth of command outputs and telemetry inputs is accomplished by adding I/O cards.

- The system, flexible multiplexer demultiplexer (FMDM), is an expanded version of the multiplexer demultiplexer (MDM) which is used on the STS orbiter.

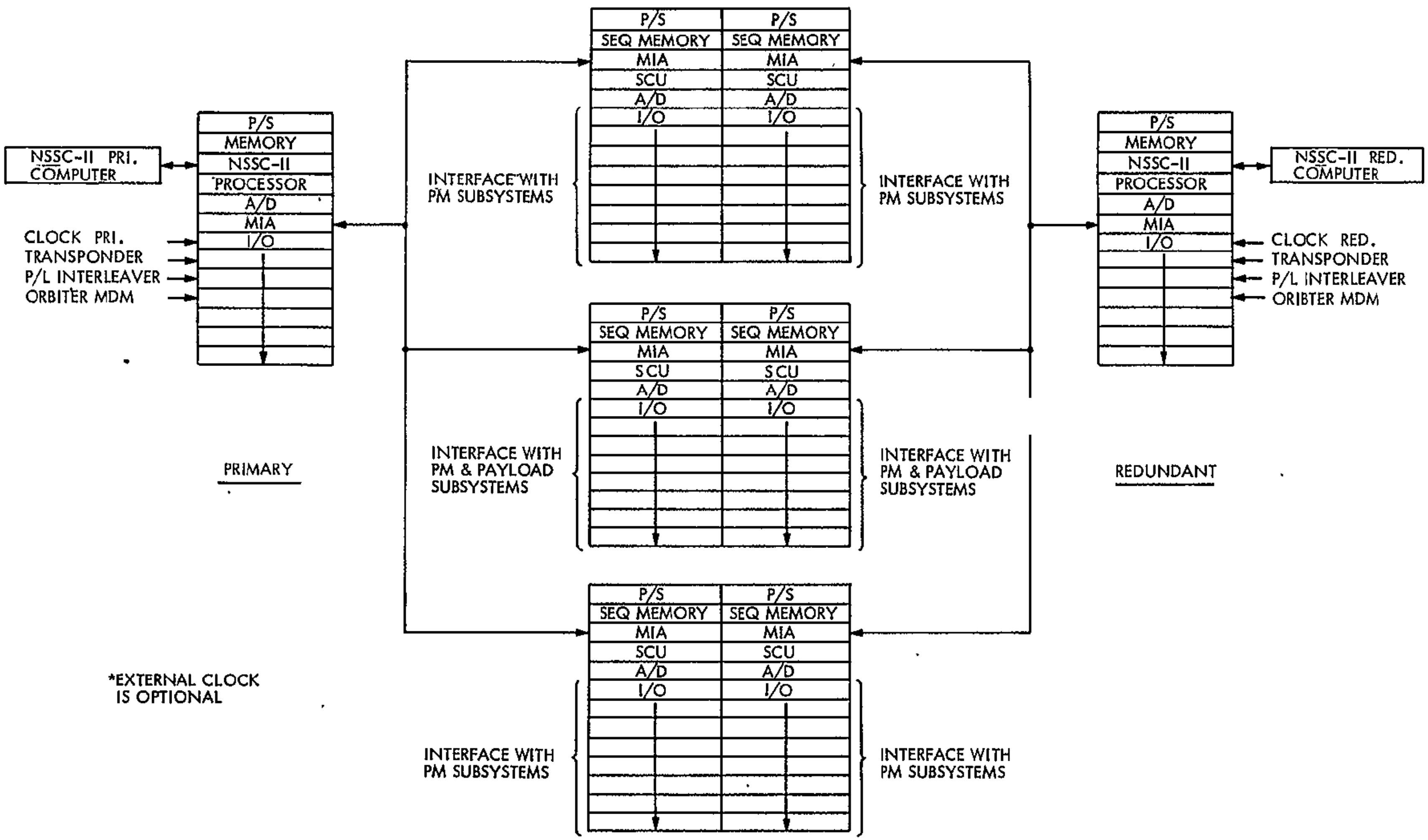
DATA HANDLING CANDIDATE-SYSTEM ONE



- This chart shows an alternate version of the FMDM system.

- The primary difference between this and candidate one is, in addition to providing a separate primary and redundant system, provisions have been made to allow internal cross-strapping by the addition of power supply, sequential memory, and the sequence control modules.

DATA HANDLING CANDIDATE-SYSTEM TWO

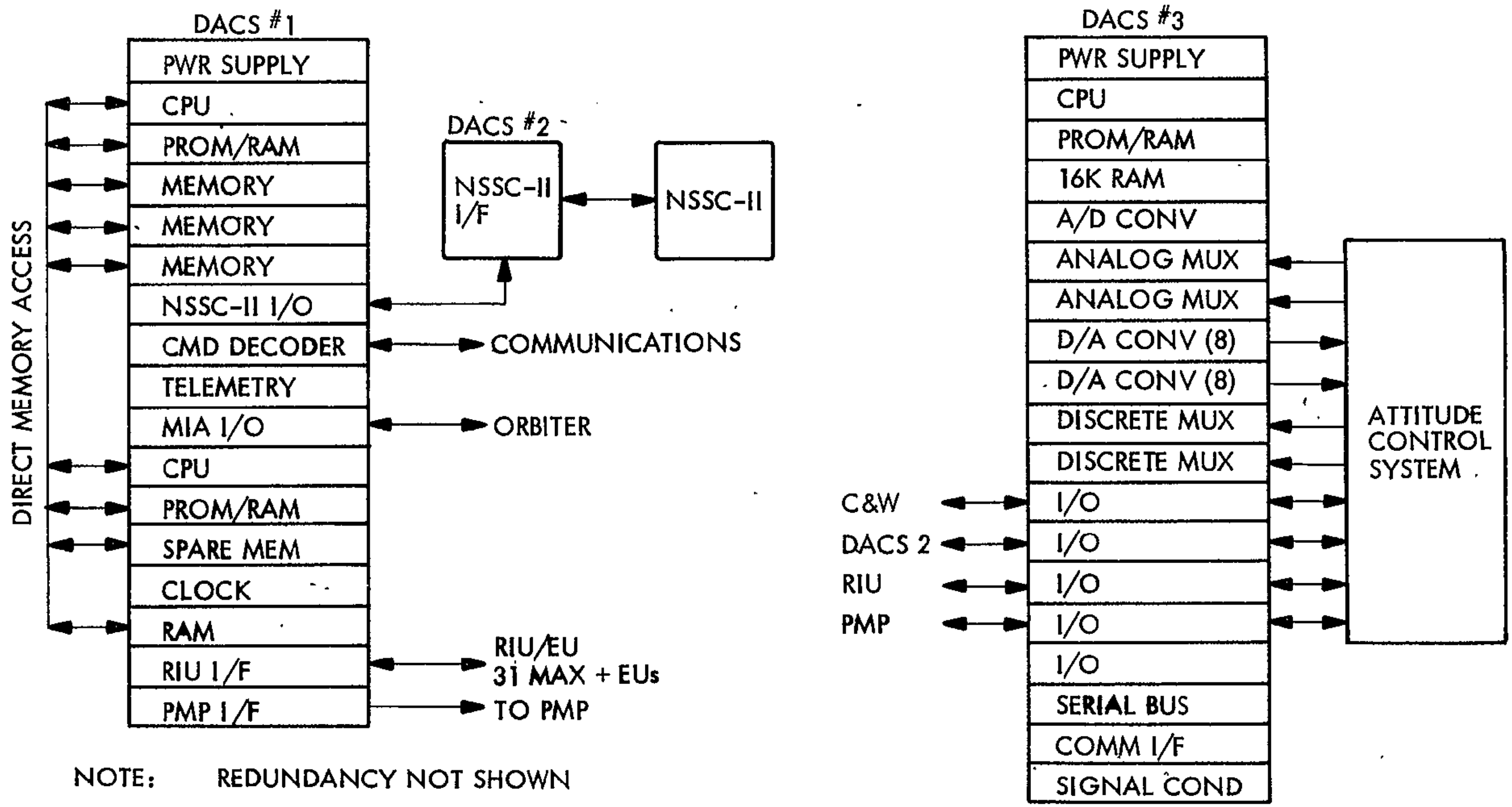


- This chart shows a microprocessor-based Data Acquisition and Control System (DACS). It provides data acquisition, data processing, control, and command operations. It provides telemetry bit rates to 256 kbs and would replace the MMS STACC, central unit, STINT II, and Power Control unit. The data processing capability of the DACS includes data accumulation, formatting, compression, time correlation, and data storage.

- A DACS has been configured to process and control the Attitude Control System routine repetitive housekeeping functions. A rough estimate indicates that this should reduce the NSSC-II computer overhead as much as 40 percent, allowing for future growth in the NSSC-II utilization.

- NSSC-II will still do the positional calculations and related decision-making algorithms.

DATA HANDLING CANDIDATE — SYSTEM THREE



NOTE: REDUNDANCY NOT SHOWN

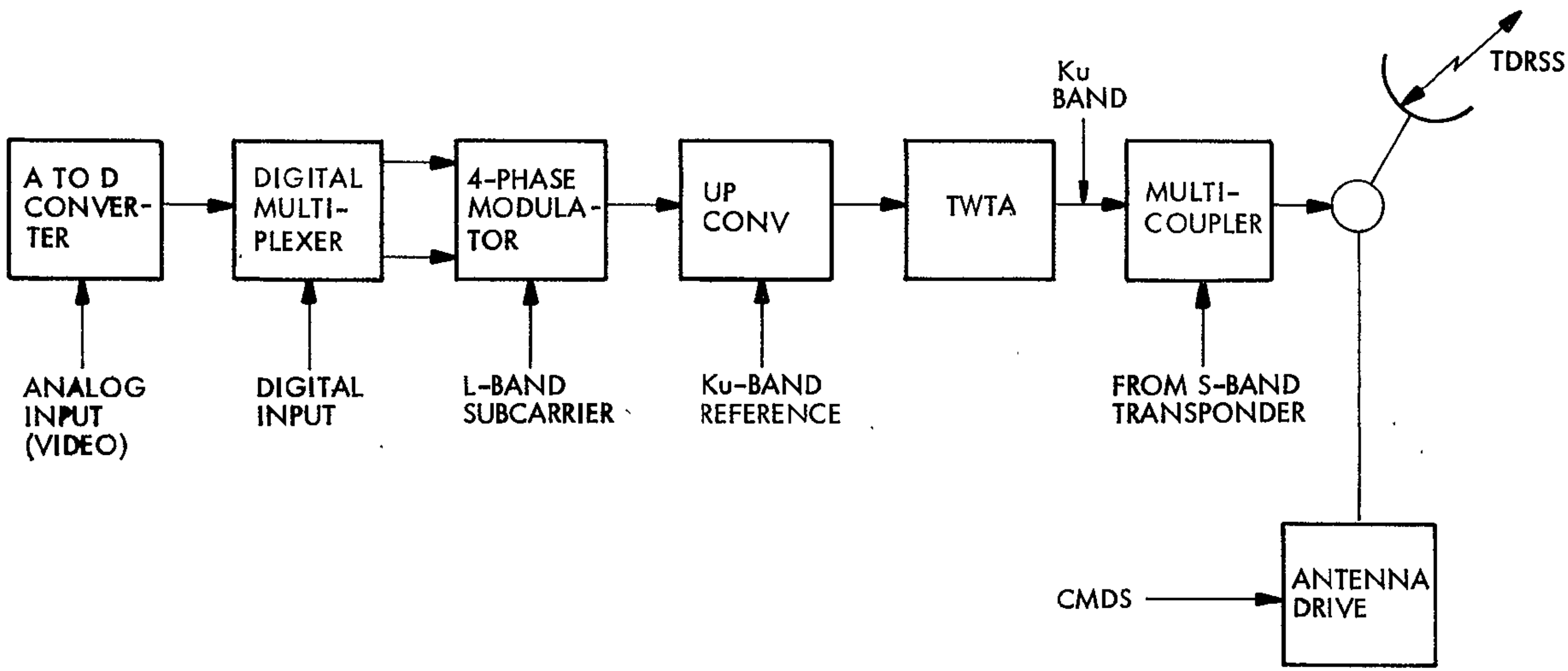
DACS	DATA ACQUISITION AND CONTROL SYSTEM
PMP	PREMODULATION PROCESSOR
RIU	REMOTE INTERFACE UNIT
EU	EXPANDER UNIT

- This chart shows a proposed high-rate data link for Solar/Terrestrial and Materials Processing missions which allows data rate growth from 256 kbs . 100 mbps.

- The system operates on the TDRSS KSA (Ku single access).

HIGH DATA RATE PCM DATA HANDLING LINK

DATA RATES TO 100 MBS



NOTE: REDUNDANCY NOT SHOWN

This chart lists recommendations for a C&DH system that satisfies all current Power Module scenarios.

C&DH SYSTEM RECOMMENDATIONS

- DELETE THE MMS C&DH SYSTEM AS A CANDIDATE DUE TO THE 64 KBS LIMITATION OF STACC.
- CHANGE THE C&DH BASELINE TO CANDIDATE ONE, TWO, OR THREE AFTER COMPETITIVELY ANALYZING EACH SYSTEM ON A TECHNICAL AND COST BASIS.
- SELECT A DISTRIBUTED-BUS SYSTEM TO ALLOW INSTALLATION OF REMOTE COMMAND AND DATA UNITS IN THE VARIOUS PAYLOADS.
- PROVIDE HIGH-GAIN ANTENNAS (HGA) WITH DUAL FEED (S AND K_u BAND).

POWER MODULE GROWTH OPTIONS

- GROWTH OPTIONS
- CANDIDATE POWER MODULES
- GROWTH KITS
- GROWTH POWER MODULE WEIGHTS

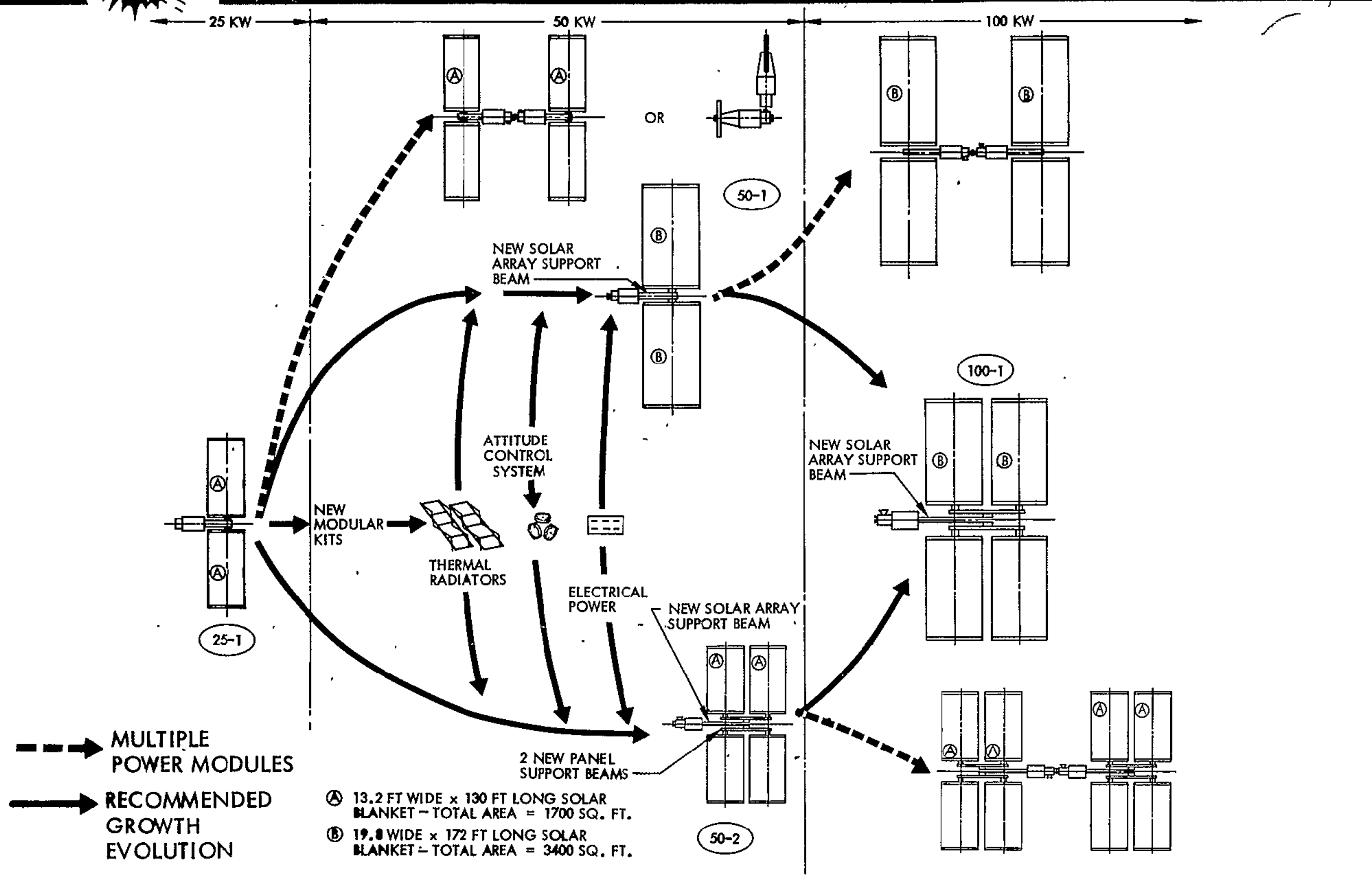
- A candidate multiple-path concept for Power Module evolutionary growth from 25 kW to 200 kW is illustrated in this and the following chart, based on subsystem growth options previously discussed.

- Technology represented in these configurations is considered "current," i.e., available for use for hardware development programs starting 1979 through 1985 (the 100 kW and 200 kW configurations are assumed to start in the later years of this period).

- The concept utilizes two sizes of solar array blankets ("A" = 13.2 x 130 ft and "B" = 19.8 x 172 ft), arranged in two, four, and eight blanket-pair configurations. The 25 kW and 50 kW sizes can be configured using two blanket-pairs, with "A" and "B" sizes, respectively. The 100 kW and 200 kW sizes can be configured using eight blanket-pairs, with the "A" size for the 100 kW and the "B" size for the 200 kW.

- Based on subsystem growth options previously reported, growth from 100 kW to 125 kW (and from 200 kW to 250 kW) is feasible with identical-size solar arrays and vehicle-configurations using 1988 technology.

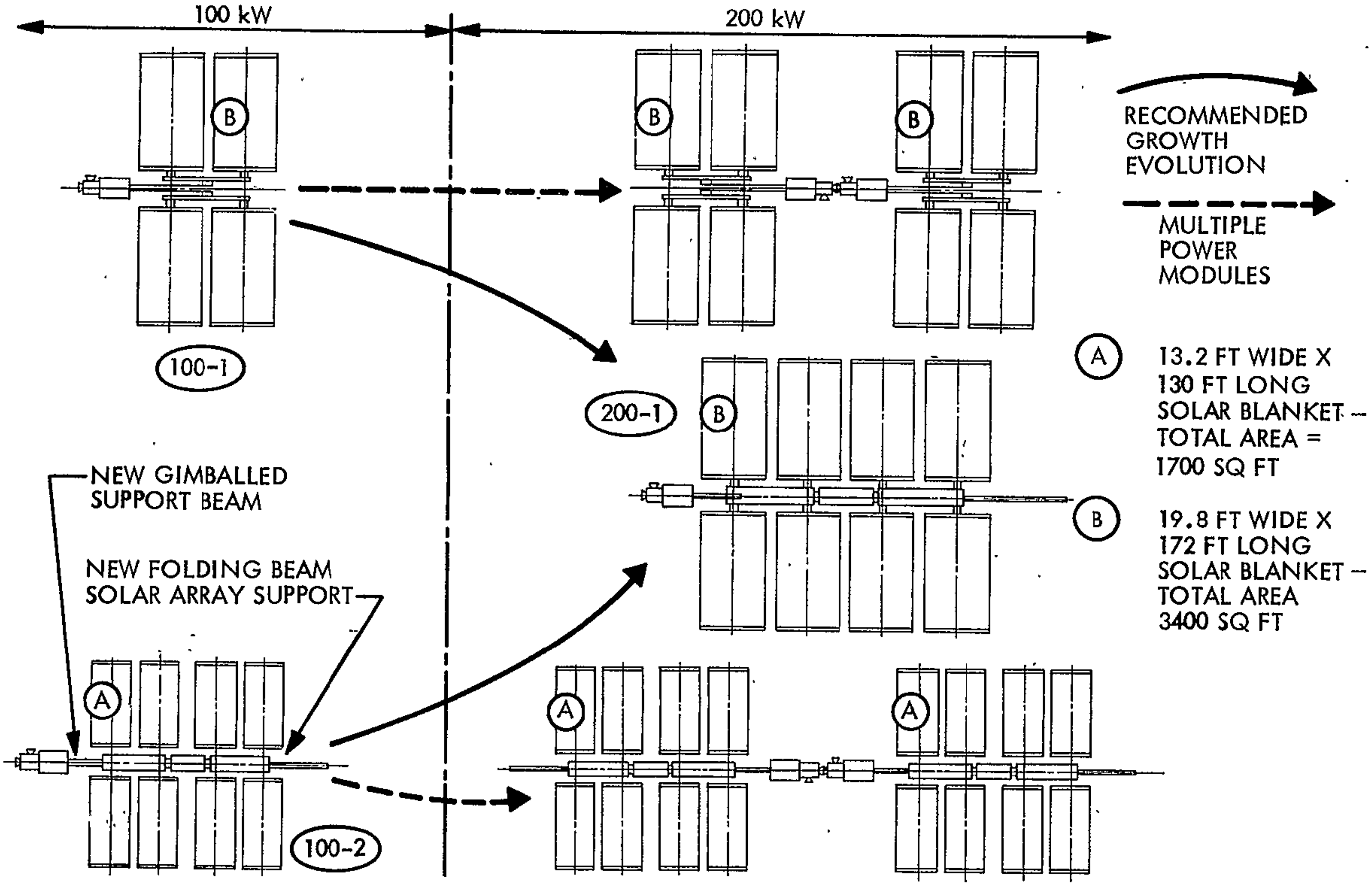
POWER MODULE GROWTH OPTIONS 25kW TO 100kW



- For the various configurations, there are appropriately sized solar-array support assemblies. The six sizes required in this multipath growth concept are illustrated.

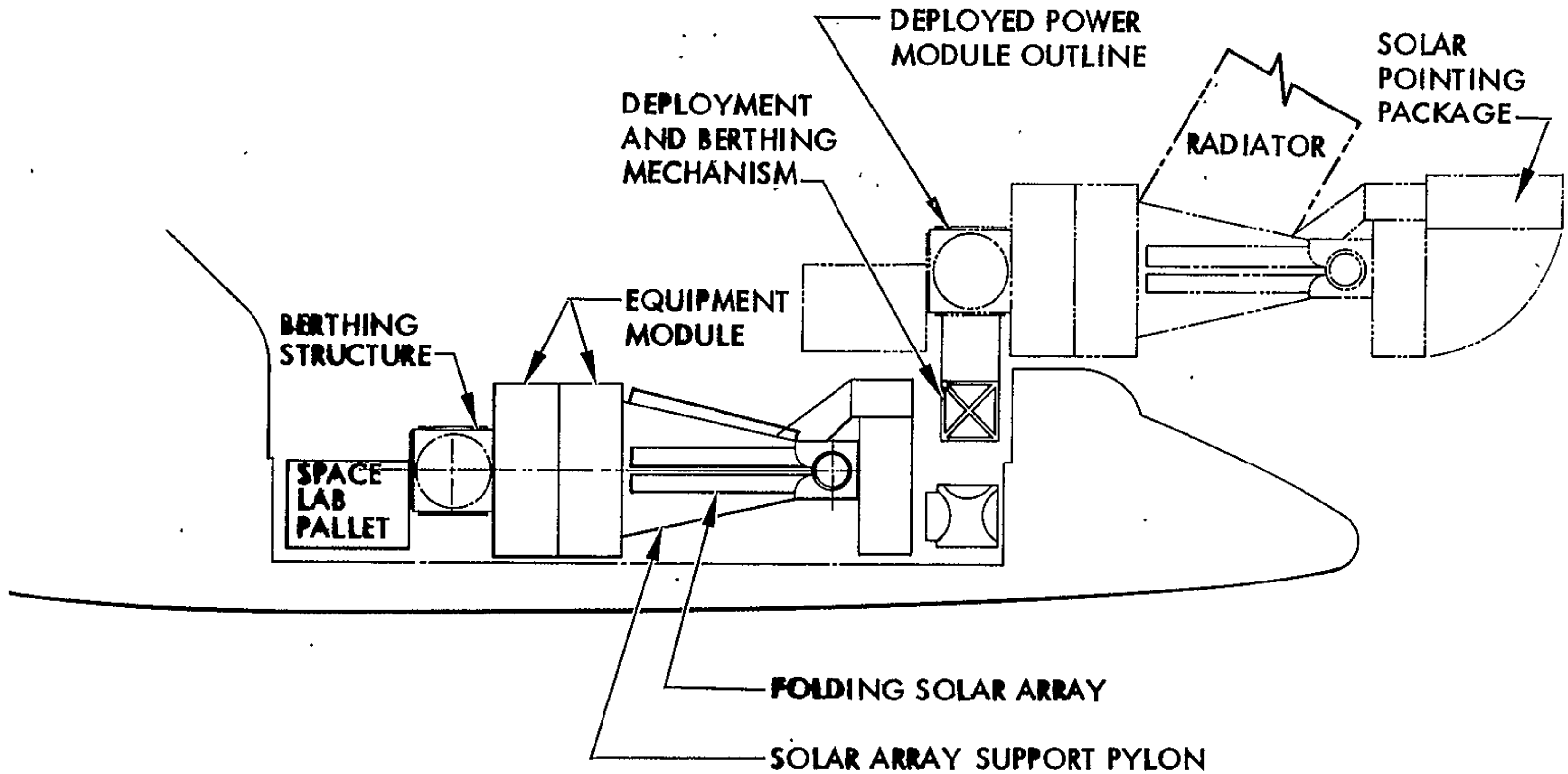
- Preliminary packaging studies indicate that the fully assembled 25 kW and 50 kW two-blanket-pair configurations can each be delivered to orbit in a single shuttle launch. The multibeam and folding-beam Power Module configurations require EVA assembly of subelements. Several packaging concepts are illustrated in subsequent charts.

POWER MODULE GROWTH OPTIONS 100 kW TO 200 kW



This configuration for a 25 kW Power Module will easily accommodate both a Spacelab pallet and a solar pointing package in one launch configuration. This permits maximum utilization of the orbiter. This reduction in overall power module length is possible because of the reduced length of the equipment structure and the folding solar arrays. The payload igloo equipments required can easily fit within the berthing structure and thereby provide maximum payload utilization of the pallet volume. The Solar Pointing Payload is erected and sun oriented after the Power Module is deployed on the orbiter.

25kW POWER MODULE LAUNCH AND DEPLOYED CONFIGURATION

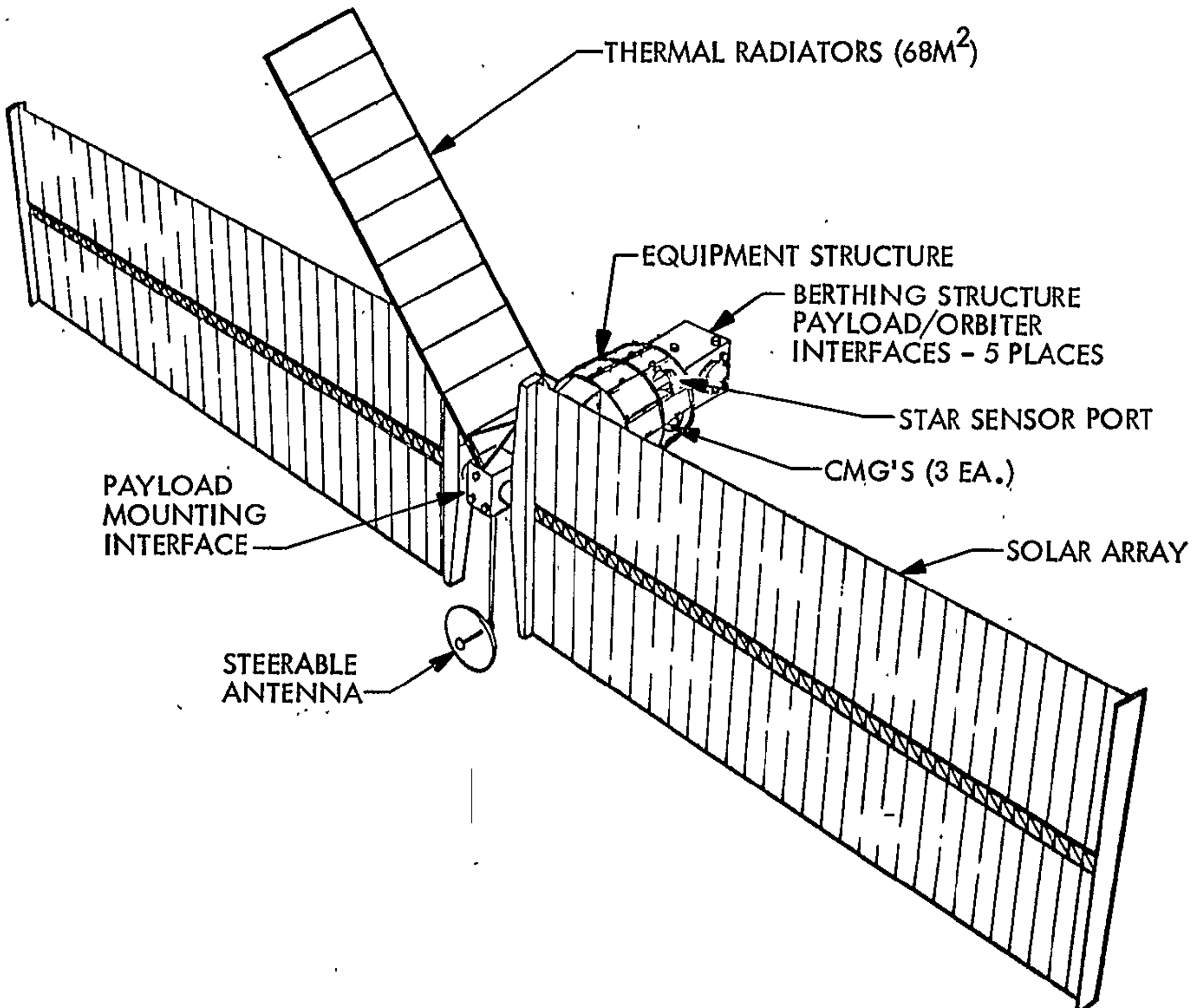


- This chart depicts the candidate configuration for the 25 kW Power Module as determined in Part II of the study.

- The configuration includes features recommended both for augmenting 25 kW free-flyer capabilities, and for enhancing ability to grow the Power Module to the higher capacity systems.

CANDIDATE 25kW POWER MODULE CONFIGURATION—DEPLOYED

1983 - 1986



- The illustration shows the Power Module both stowed in the Orbiter payload compartment and deployed in a sortie mode attached to the Orbiter.

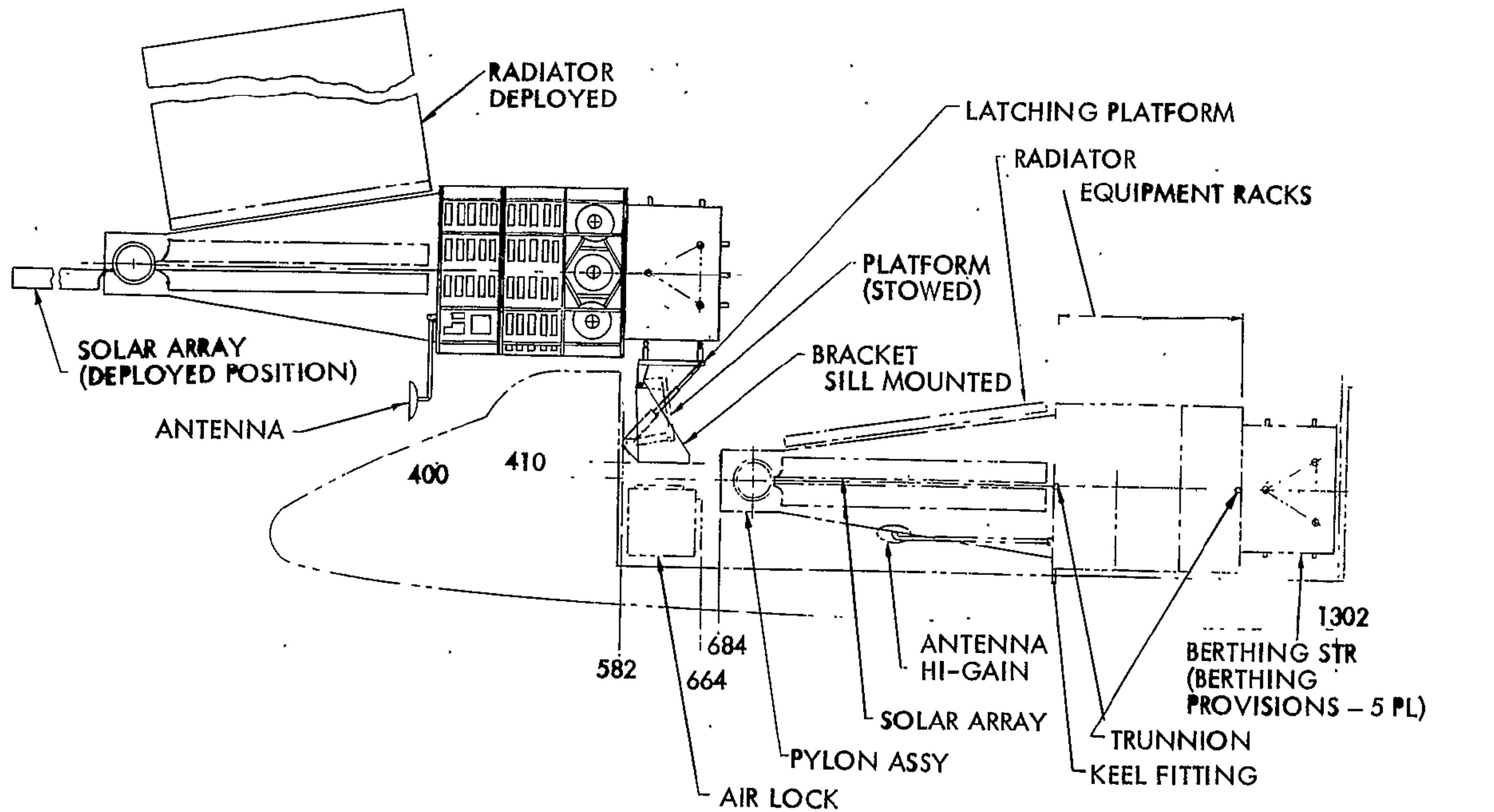
- The Power Module main-structure assembly consists of three equipment segments to which are attached a semimonocoque support structure that carries the 50 kW solar array, the thermal radiators, and associated equipment.

- At the aft end of the equipment rack is a semimonocoque support structure carrying a latching/berthing system on each of its five faces.

- The equipment rack carries:
  - The attitude control system (six control moment gyros).
  - Communication and data handling system (two high-gain antennas are attached to the forward face of the equipment rack).
  - The electrical power system, including batteries, transformers, etc.

- In the sortie mode the Power Module is berthed and secured by its latching system upon a deployed berthing platform at shuttle STA X=619.

CANDIDATE 50kW POWER MODULE



- The chart shows the assembled 100 kW Power Module in a free-flyer mode. The Power Module has been assembled by RMS-assisted EVA from components supplied in two Space Shuttle loads.

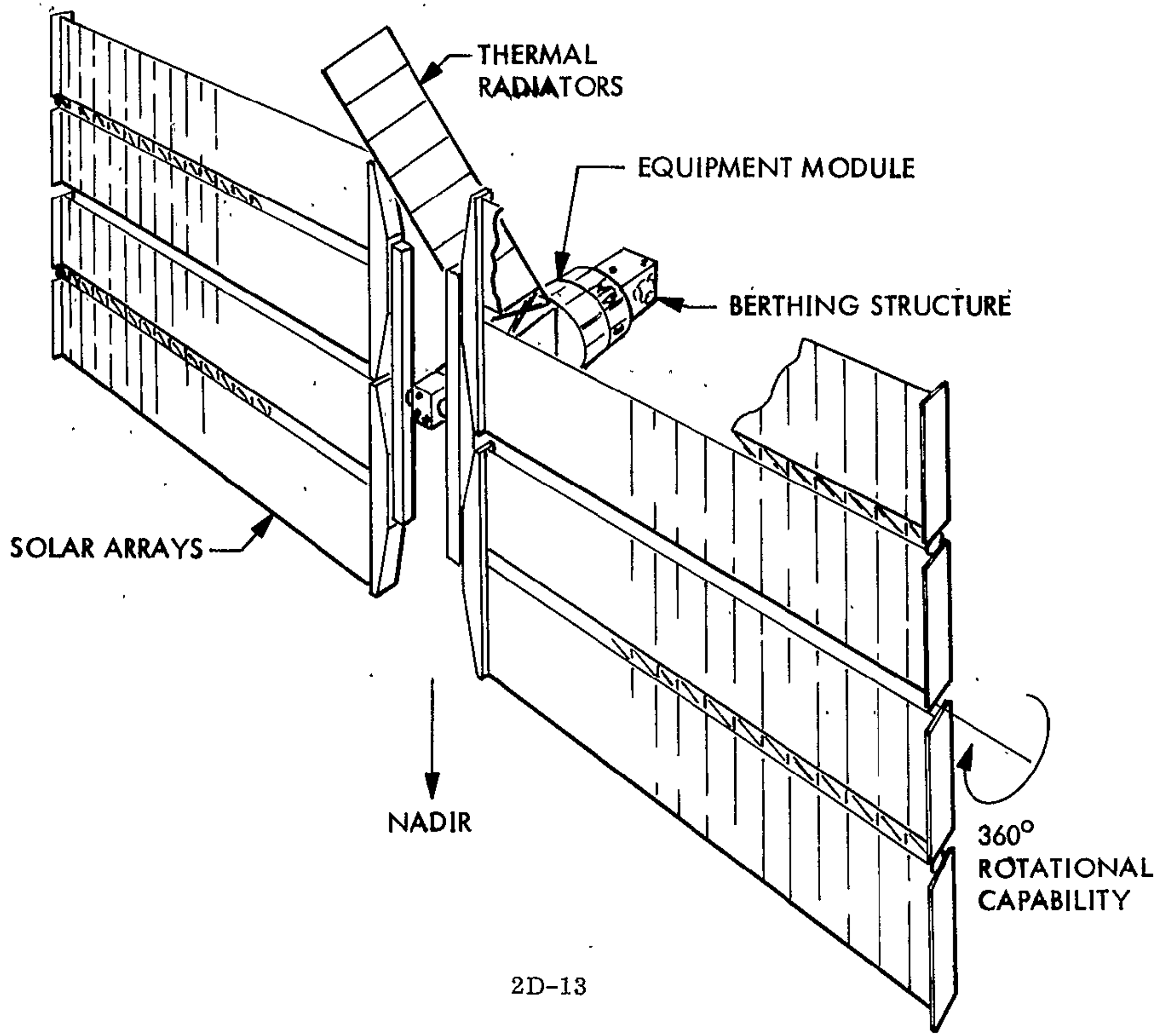
- The assembly operations required are:

  - The installation of the support boom gimbal unit between the two solar array beams.

  - The installation of the other end of the support boom to the forward face of the equipment rack.

- After the foregoing assembly operations are completed, the solar array and thermal radiator panel extension mechanisms are activated to deploy those units.

CANDIDATE 100/125 kW POWER MODULE (DEPLOYED)

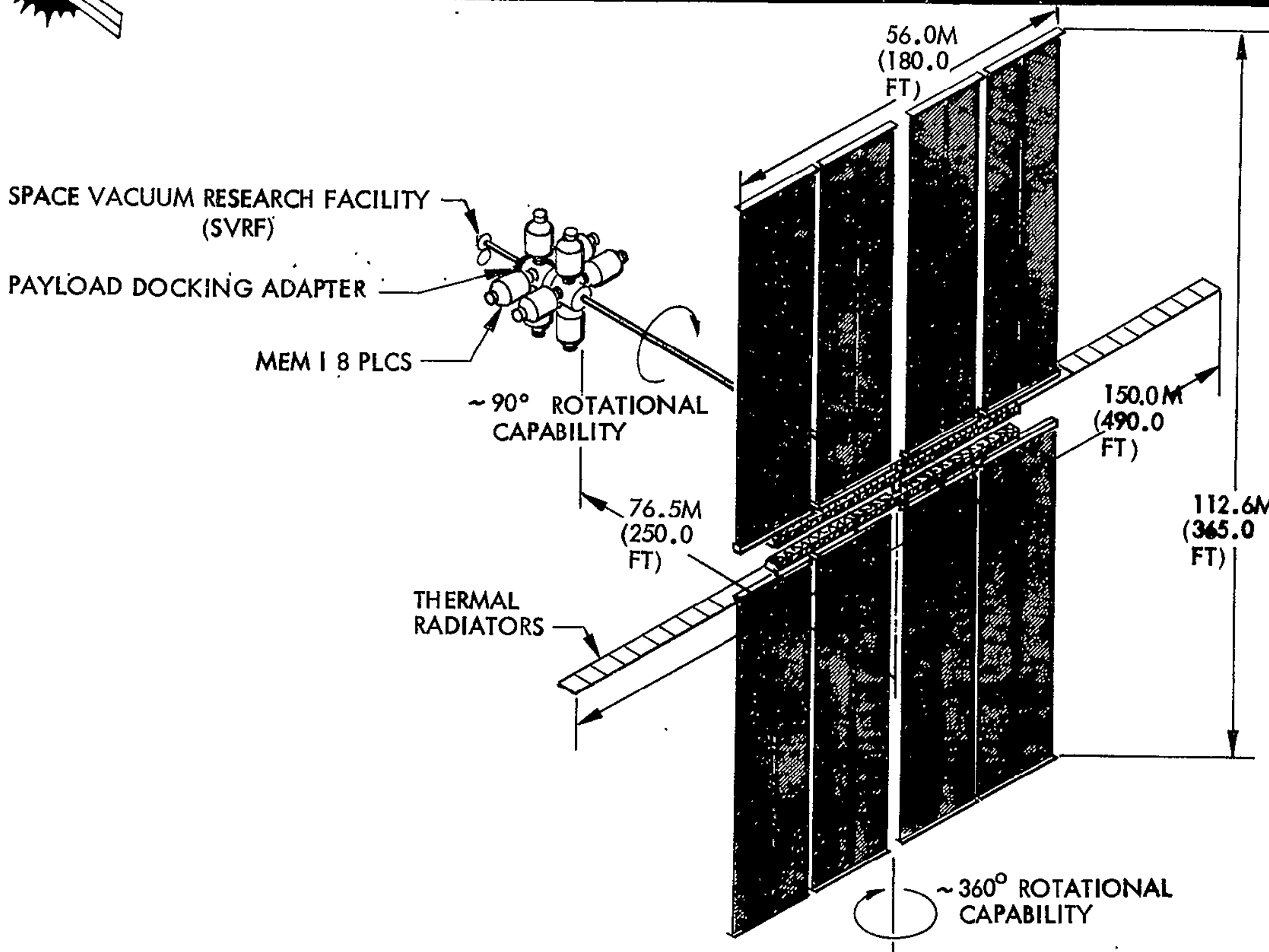


- The chart depicts a solar array arrangement suitable for delivery, deploying, and manipulating solar blankets of sufficient area to develop from 200 to 250 kW average power on-orbit. It contains eight pairs of blankets, of the 19.8 x 172 ft size. The concept enables an orderly Power Module growth evolution from 25 to 250 kW. The 200 kW configuration uses four of exactly the same blanket subassemblies as those employed on the 50 kW configuration identified as No. 50-1 on the previous growth option chart (for 25 kW to 100 kW, see page).

- When this folding-beam concept is designed for use with the smaller blankets used with the proposed baseline 25 kw Power Module, a 100/125 kW capability is achieved. The difference between 100 to 125 kW (as well as the 200 to 250 kW) configurations is basically a shift to more advanced technology, i.e., shifting from Silicon to Gallium-Arsenide solar cells. (See discussion under "Electrical Power Subsystem Growth" page).

- This packaging concept is configured to fit the volume and mounting constraints of the Orbiter payload bay. As with the previously described multiple-beam configurations, RMS assisted EVA assembly to a PM equipment module or payload already available on-orbit must be effected when implementing this configuration. (See next chart showing an intermediate stage in this on-orbit assembly.)

200/250 kW POWER MODULE (DEPLOYED)



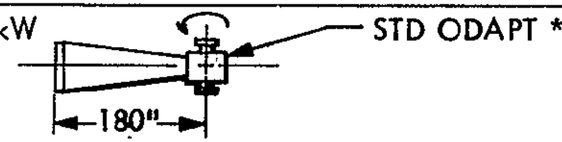
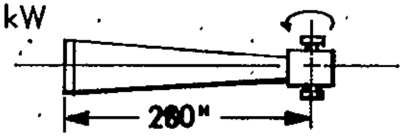
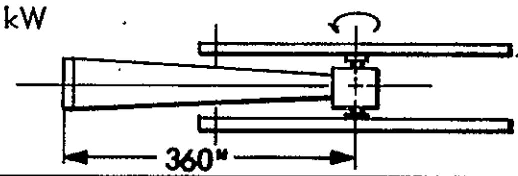
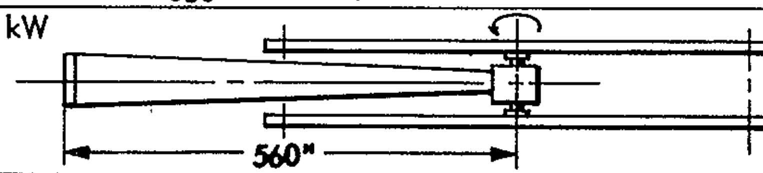
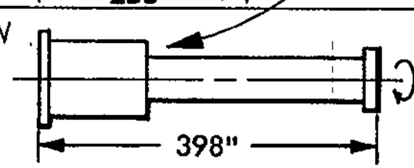
- The two fixed and two multiple beam solar array support assemblies are of similar design, scaled to accommodate the increased sizes of solar arrays.

- Solar array rotation for the two large folded beam configurations can readily be accomplished around the Power Module X-X axis in lieu of the Y-Y axis. For these, the solar array support assembly has one large orientation drive and power transfer (ODAPT) assembly in lieu of the standard pair of ODAPTs that are utilized in the smaller Power Modules.

- The beam assemblies are modular, with a standard interface to the equipment rack assembly. The design will provide for on-orbit maintenance/replacement of the complete assembly, individual solar array/mast/cannister subassemblies, and ODAPT assemblies.

- For all configurations the desirability of having two-axis solar array pointing warrants trade study consideration. With the smaller configurations it can be accomplished by providing an additional ODAPT assembly at the base of the fixed beam (as shown on the chart for the 100 kW and 200 kW support assemblies). For the large folded-beam configurations it requires that the beam be split (see the 200-250 kW configuration charts).

SOLAR ARRAY SUPPORT ASSEMBLY, GROWTH FROM 25 kW TO 200 kW

	PANEL QTY	SIZE (FT)	TYPE BEAM
25 kW 	4	13	FIXED
50 kW 	4	20	FIXED
50 kW 	8	13	FIXED
100 kW 	8	20	FIXED
100 kW 	16	13	GIMBAL
200 kW 	16	20	GIMBAL

*ODAPT:
ORIENTATION DRIVE
& POWER TRANSFER
ASSEMBLY

- The chart illustrates packaging, in the Orbiter payload compartment, of a growth kit for changing a 25 kW Power Module into a 50 kW Power Module. Subassemblies in the kit are described below.

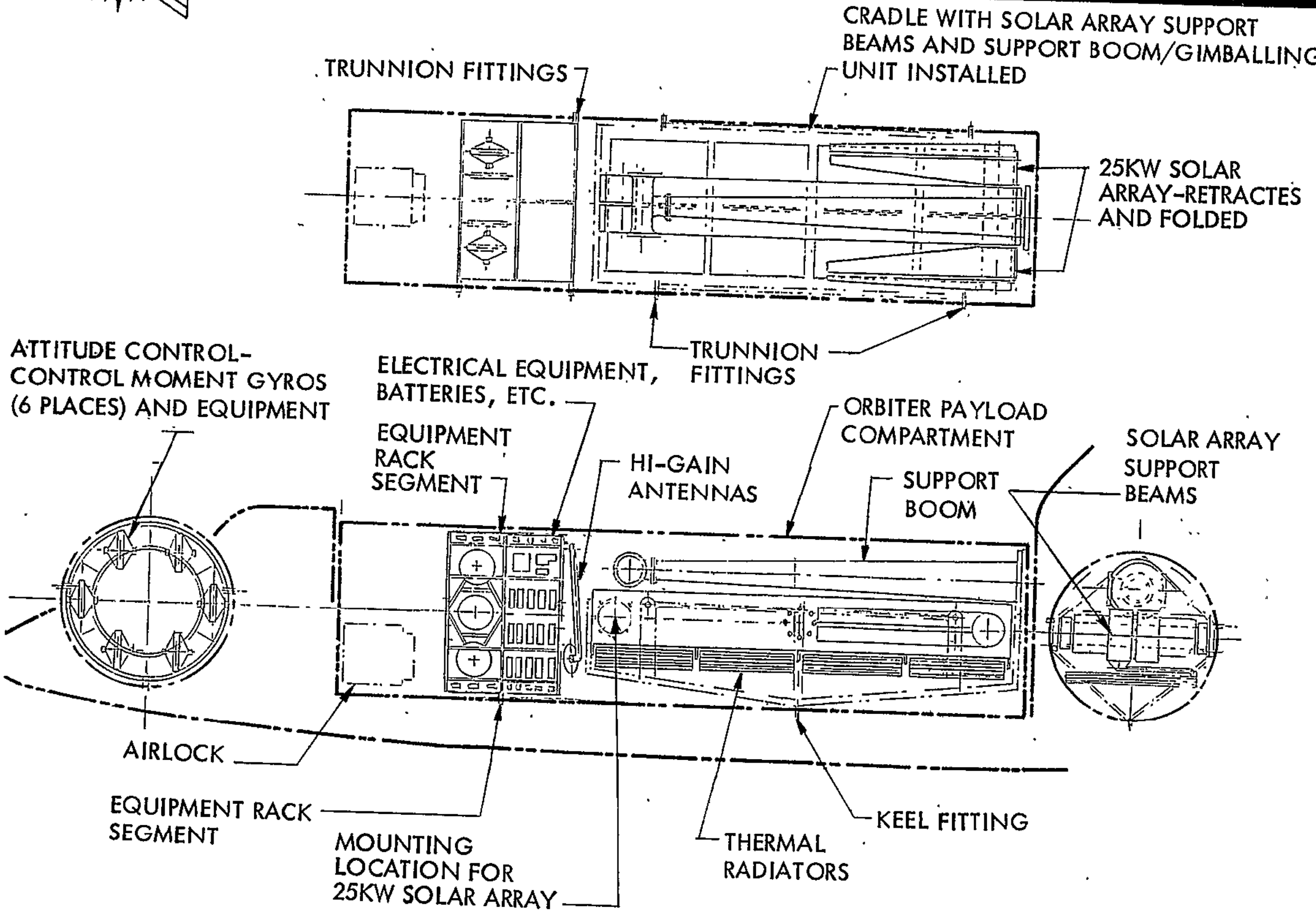
- A forward equipment rack section carries a high-gain antenna, six control moment gyros, and the required additional electrical batteries and associated equipment.

- Two solar array support beams are provided, each with on alf of the 25 kW solar array and a standardized installation/mount for the 25 kW solar arrays taken from the orbiting 25 kW Power Module. One support beam carries the required thermal radiators for a 50 kW Power Module.

- A support beam containing a gimballing unit, to be installed between the solar array beams, gives the solar array system a two degree-of-freedom pointing capability. The other end of the support beam will be attached on-orbit to the equipment rack.

- These units are installed in the Orbiter payload bay in a packaging cradle that is attached to the orbiter trunnions and keel fitting. This cradle will be designed to receive and return to earth those components of the orbiting 25 kW Power Module that are replaced by the 50 kW growth components.

ORBITAL GROWTH KIT-25-50 kW



- The chart illustrates packaging, in the Orbiter payload compartment, of a growth kit for changing a 50 kW Power Module into a 100 kW Power Module. To secure these components in the Orbiter payload "A" compartment, they are installed in a packaging cradle that attaches to the Orbiter trunnions and keel fitting. Subassemblies in the kit are described below.

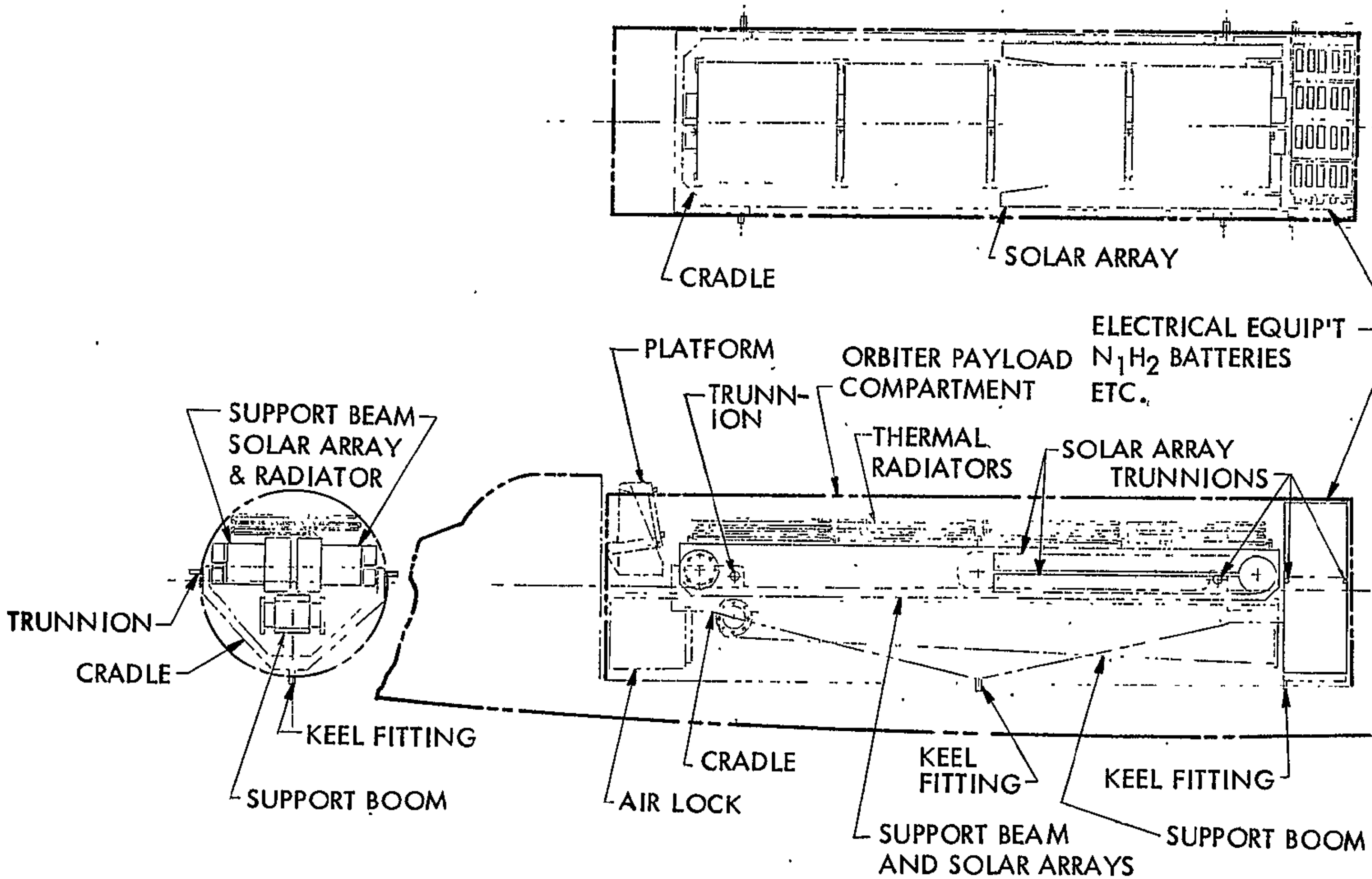
- A new equipment rack section is provided containing an electrical power system using NiH_2 batteries and associated cabling and equipment.

- Two solar array support beams are provided, each beam containing one-half of a 50 kW solar array and a standardized installation/mount for attaching the 50 kW solar array removed from the orbiting 50 kW Power Module. One of these solar array support beams carries the required thermal radiators and associated equipment for a 100 kW system.

- A support beam containing a gimballing unit to be installed on-orbit between the two solar array support beams, provides the array with a two degree-of-freedom pointing capability. The other end of the support beam is assembled to the equipment rack.

- The packaging cradle is designed to be utilized for the return of the components of the 50 kW Power Module that are replaced by the 100 kW growth components.

OPTIONAL GROWTH KIT – 50-100 kW



- The solar array and support beams, equipment rack, and support boom for the 100 kW Power Module will require more than one Orbiter-delivery to orbit. This chart illustrates the stowage arrangement of components in the first Shuttle load.

- The major components are: two solar array support beams are provided each carrying two halves of a 50 kW solar array, and a support boom with a gimballing unit attached.

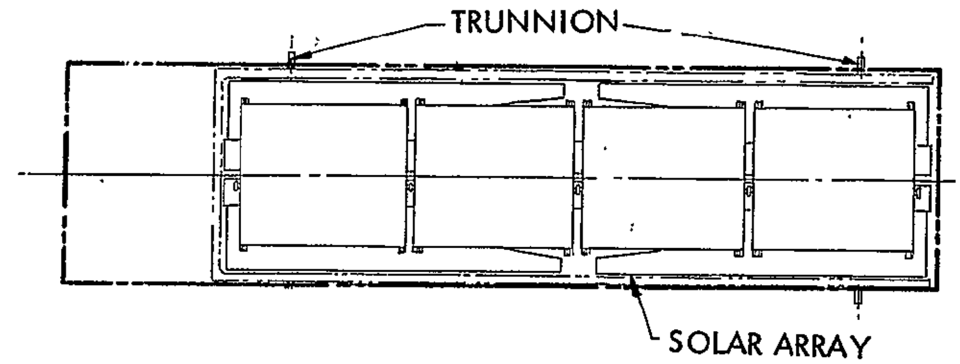
- Each solar array support beam has a standardized mounting interface at the center of the beam which will be assembled (during orbit assembly) to the support boom gimbal unit.

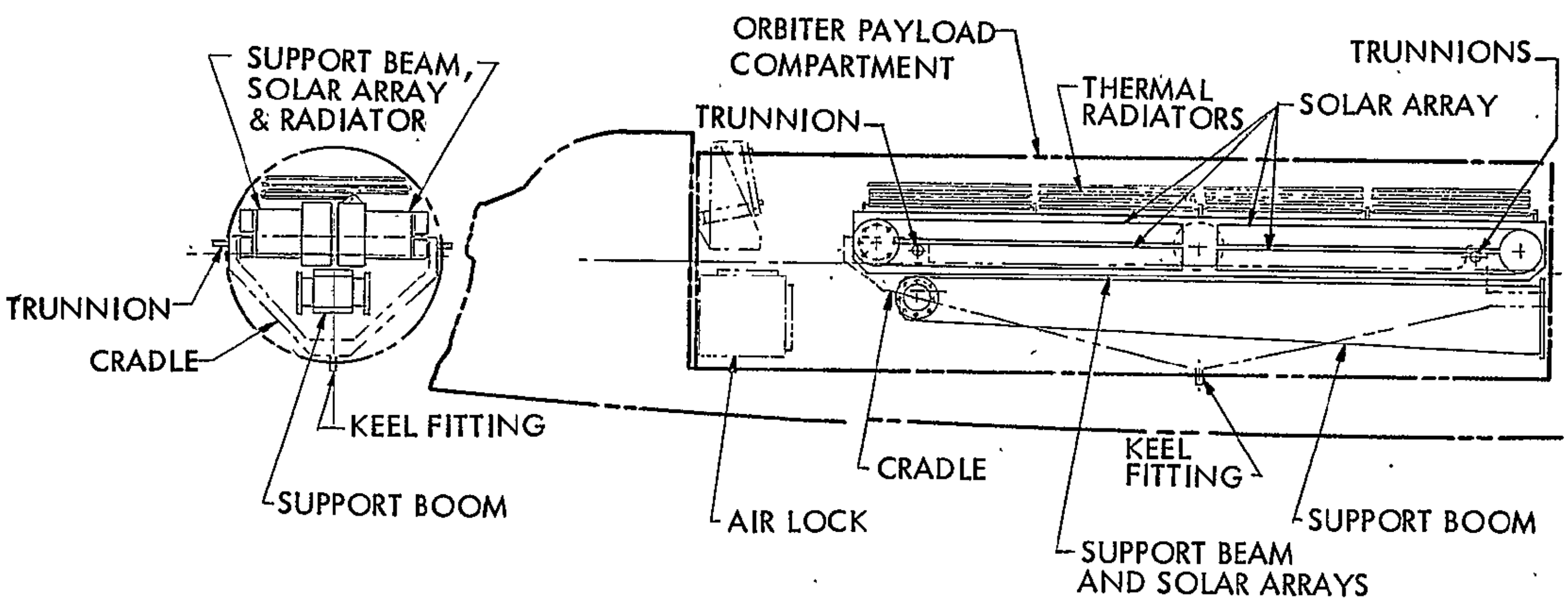
- Thermal radiators, folded for stowage, are attached to one of the solar array support beams. The support boom is fitted with a "V" band type attachment ring at one end for final attachment to the equipment rack.

- All these components are packaged in a cradle that is attached to and transfers the loads to the Orbiter trunnions and a keel fitting.

100 kW PM — OPTIONAL CONFIGURATION

NO. 1 OF TWO SHUTTLE LOADS





- The equipment rack and berthing support structure for the 100 kW Power Module will be carried to orbit in the second of the two Shuttle loads.

- The rack and support structure will be a structurally integrated unit, and attached to the Orbiter trunnions and a keel fitting. The rack will contain:

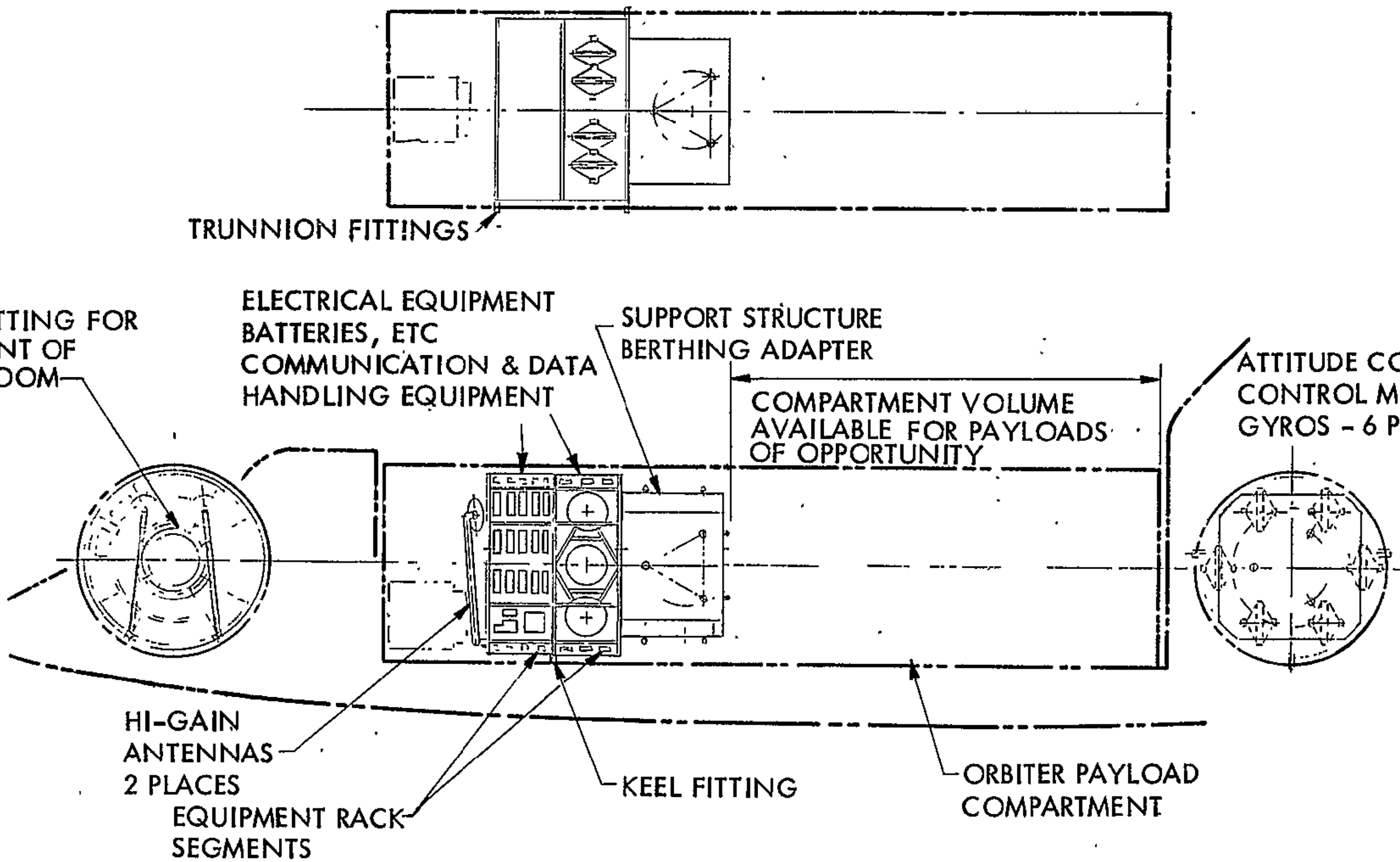
  - The attitude control system (with six control moment gyros)
  - Electrical power system with NiH_2 batteries and associated equipment
  - Communications and data handling equipment (with two high-gain antennas attached to the forward face of the rack).

- The berthing support structure carries a berthing latching system on each of its five faces.

- This loading arrangement will leave space in the payload compartment for the installation of pallets and other payloads of opportunity.

100 kW PM — OPTIONAL CONFIGURATION

NO. 2 OF TWO SHUTTLE PAYLOADS



- The chart shows an intermediate stage in the on-orbit assembly of the 200/250 kW Power Module. The upper and lower support beam assemblies that are folded and connected together during their transportation in the STS, have been removed by RMS from the Orbiter bay and are shown disconnected and partially unfolded.

- Each support beam assembly consists of a center beam truss to which is hinged at either side, an outer support beam truss. These outer support beams carry the solar arrays. Equipment can be carried in the center beam.

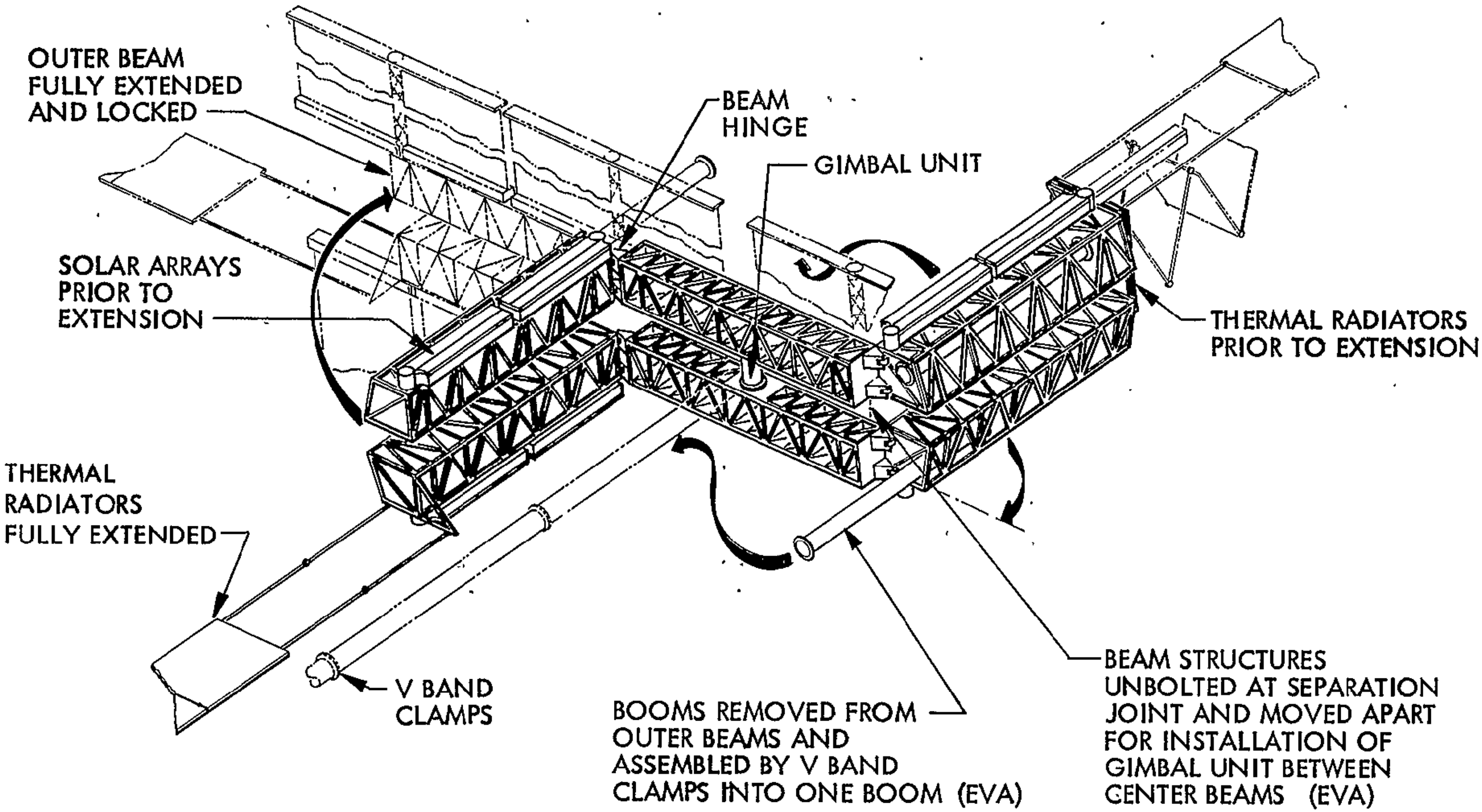
- In the illustration, a gimballing unit has been removed from its stowage within an outer support beam and has been attached to the upper and lower center beams, separating the two support beam assemblies.

- Two lengths of the support boom have been removed from their stowage within the outer support beams and are shown assembled by V-band clamps and attached to the gimballing unit. The other two lengths of the support boom are shown partially removed from their stowage.

- Thermal radiator panels are attached to the outer ends of the outer support beams. These are stowed in a folded condition during transportation by Orbiter and are shown partially extended.

- Upon final assembly of the four lengths of support boom, the support beams can be fully unfolded and locked, and the solar arrays can be extended.

250 kW POWER MODULE SYSTEM



- In the section "Subsystem Growth," previous charts have summarized initial weight estimates for the subsystems. These preliminary weight estimates will be massaged and improved as part of the Part III studies. It is considered potentially feasible, for example, that the total weight of the 200 and 250 kW Power Module systems can be reduced from 75,000 lb to the maximum Orbiter delivery capability of 65,000 lb, as the design is developed and the 25 percent contingency weight allowance is depleted.

- In the 100-kW and 200 kW configurations, which are not required until 1985 or later, the following has been presumed: (1) Nickel-Hydrogen batteries are utilized (with much greater depth of discharge), and (2) higher voltage systems are employed. Together, these provide a considerable reduction in electrical power subsystem weight per unit of power produced.

- Under the label "1988 Technology," the following has been presumed: (1) solar blanket sizes remain the same as for the earlier 100 kW and 200 kW concepts, (2) GaAs solar cells replace the silicon cells (a 25% increase in power output), and (3) material technology provides some structural weight reductions. (Refer to discussions in Electrical Power and Structural Subsystem sections). Together these provide for growth from 100 kW to 125 kW, and from 200 kW to 250 kW, without change in overall physical configuration of the two largest-sized Power Modules.

TOTAL POWER MODULE GROWTH WEIGHTS

POWER	CURRENT TECHNOLOGY*				1988 TECHNOLOGY	
	25 KW	50 KW	100 KW	200 KW	100 KW	200 KW
WEIGHTS - LB.						
STRUCTURE & MECH.	6,550	2,450	9,300	12,700	8,450	11,300
ELECTRICAL POWER	12,010	23,640	19,050	35,900	16,050	30,000
THERMAL CONTROL	2,226	4,750	4,835	8,050	2,530	4,771
ATTITUDE CONTROL	2,175	3,982	4,406	4,851	4,406	4,851
C & DH	515	537	559	581	502	502
SUBTOTAL	23,476	41,359	38,150	62,082	31,938	51,446
CONTINGENCY - 25%	5,869	10,340	9,538	15,521	7,984	12,861
TOTAL	29,345	51,699	47,688	77,603	39,922	64,307

* EXCEPT FOR USE OF 1980-1985 TECHNOLOGY NICKEL-HYDROGEN BATTERIES

ELECTRICAL POWER SUBSYSTEM GROWTH WEIGHTS

	CURRENT TECHNOLOGY				1988 TECHNOLOGY	
POWER	25 KW	50 KW	100 KW	200 KW	100 KW	200 KW
CELL TYPE, LB/FT^2	Si, 0.2	Si, 0.2	Si, 0.15	Si, 0.15	GaAs, 0.1	GaAs, 0.1
BATTERY, DOD	NiCd, 22%	NiCd, 22%	NiH_2, 64%	NiH_2, 80%	NiH_2, 64%	NiH_2, 80%
VOLTAGE	28	28	110	220	110	220
WEIGHTS - LB.						
SOLAR ARRAY	2,400	4,850	8,400	16,700	5,600	11,200
BATTERIES	7,440	14,880	6,650	11,200	6,650	11,200
ELECTRONICS	1,320	2,640	2,400	4,800	2,400	4,800
POWER DISTRIBUTION	250	470	600	1,200	600	1,200
CABLING	600	800	1,000	2,000	800	1,600
SUBTOTAL	12,010	23,640	19,050	35,900	16,050	30,000
CONTINGENCY - 25%	3,003	5,910	4,763	8,975	4,013	7,500
TOTAL	15,013	29,550	23,813	44,875	20,063	37,500

THERMAL CONTROL SUBSYSTEM GROWTH WEIGHTS

POWER	CURRENT TECHNOLOGY				1988 TECHNOLOGY	
	25 KW	50 KW	100 KW	200 KW	100 KW	200 KW
RADIATOR AREA - FT^2	630	1,350	1,160	1,160	720	1,440
WEIGHT - LB.						
RADIATOR	882	1,890	1,620	1,620	864	1,440
COLD PLATES, LINES	680	1,458	1,660	3,320	778	1,555
PUMPS, CONTROLS	514	1,102	1,255	2,510	588	1,176
MLJ, PAINT, MISC.	150	300	300	600	300	600
SUBTOTAL	2,226	4,750	4,835	8,050	2,530	4,771
CONTINGENCY - 25%	557	1,188	1,209	2,013	633	1,193
TOTAL	2,783	5,938	6,044	10,063	3,163	5,964

ATTITUDE CONTROL SUBSYSTEM GROWTH WEIGHTS

POWER	CURRENT TECHNOLOGY				1988 TECHNOLOGY	
	25 KW	50 KW	100 KW	200 KW	100 KW	200 KW
WEIGHTS - LB.						
CMG'S & INVERTERS	1,416	2,832	2,832	2,832	NO SIGNIFICANT WEIGHT CHANGE	
RATE GYROS	104	35	35	35		
SLG. COND., I/F UNITS	90	90	90	90		
STAR TRACKERS & SHADES	87	87	87	87		
MAG. TORQUERS & ELECT	460	920	1,344	1,789		
MISC.	18	18	18	18		
SUBTOTAL	2,175	3,982	4,406	4,851		
CONTINGENCY - 25%	544	996	1,102	1,213		
TOTAL	2,719	4,978	5,508	6,064		

C&DH SUBSYSTEM GROWTH WEIGHTS

	CURRENT TECHNOLOGY				1988 TECHNOLOGY	
POWER	25 KW	50 KW	100 KW	200 KW	100 KW	200 KW
WEIGHTS - LB.						
TRANSPONDERS	31	31	31	31	31	31
NSSC-II	161	161	161	161	80	80
CENTRAL & REMOTE UNITS	132	154	176	198	118	118
ANTENNAS & DRIVES	119	119	119	119	119	119
STEERING ELECTRONICS	48	48	48	48	30	30
CABLING & SWITCHES	24	24	24	24	24	24
SUBTOTAL	515	537	559	581	402	402
CONTINGENCY - 25%	129	134	140	145	100	100
TOTAL	644	671	699	726	502	502

SUPPORT ELEMENT GROWTH POTENTIAL

- The baseline Skylab crew support can be expanded from three to seven by the addition of sleeping facilities and increasing the provisions on board. Introduction of a Power Module to provide additional electrical power for experiment support will require use of a pressurized Payload Docking Module element. Power requirements shown are based on a 22 kW housekeeping requirement for manned Skylab, 14 kW unmanned, and a growth in experiment power requirement from 8 to 50 kW (in 1988) based on Material Processing data. The heat rejection capability of Skylab is 22 kW. To provide free-flying manned capability, a substantial communication capability must also be added.

- Other data on the chart are self-explanatory. The quantities shown and the observations generated are derived from information contained in the McDonnell Douglas and Martin Marietta skylab reuse study reports. (References are identified in the appendix)

SKYLAB GROWTH EVOLUTION

MISSION	SKYLAB MODIFICATIONS REQUIRED	MISSION DURATION DAYS	ORBITER MODIFICATIONS REQUIRED	AVERAGE POWER REQUIREMENT (kW)	PM SUPPLIED PAYLOAD THERMAL CONTROL (kW)
EXTENDED SORTIE	NONE	30	MODULAR ADAPTER WITH PM	25	3
MEDIUM-DURATION SORTIE	EXPAND HABITABILITY SYSTEM. DOCKING MODULE REQUIRED	60	MODERATE IMPROVEMENT WITH PM	50	28
LONG-DURATION SORTIE	EXPAND HABITABILITY SYSTEM. DOCKING MODULE REQUIRED	90	EXTENSIVE IMPROVEMENT WITH PM	50	28
FREE-FLYING UNMANNED	NONE	90+	N/A	40 TO 65	18 TO 43
FREE-FLYING MANNED	COMMUNICATION KIT REQUIRED. EXPAND HABITABILITY SYSTEM. DOCKING MODULE REQUIRED	90+	N/A	50 TO 175	28 TO 153
SPACE PLATFORM OR SPACE CONSTRUCTION BASE	EXPAND HABITABILITY SYSTEM. DOCKING MODULE REQUIRED	90+	NONE, TOO EXTENSIVE	250	228

- The projected Spacelab growth evolution, as proposed by the ERNO study (referenced earlier) is summarized in the chart. The quantities indicated under "power required" and "thermal control requirements" represent a synthesis of a matrix of optional developmental/evolutionary paths, leading ultimately to a large manned space platform or space construction base. In essentially all of these projections, considerable power augmentation is required; all free-flyers require attitude stabilization and control for solar array and payload pointing.

- Some of the growth concepts involve a train of modules attached to a Power Module in a free-flying mode. In most cases, as a consequence of distance from the Power Module, at least the outer module(s) of a train would be equipped with its own thermal control system rather than dependence upon the Power Module for heat rejection.

SPACELAB GROWTH EVOLUTION

MISSION	SPACELAB MODIFICATIONS REQUIRED*	MISSION DURATION (DAYS)	ORBITER MODIFICATIONS REQUIRED	AVERAGE POWER REQUIREMENT** (kW)	PM SUPPLIED PAYLOAD THERMAL CONTROL (kW)
EXTENDED SORTIE	MINOR IMPROVEMENT	30	MODULAR ADAPTER WITH PM	7 TO 15	0 TO 8
MEDIUM-DURATION SORTIE	MODERATE IMPROVEMENT	60	MODERATE IM-PROVEMENT WITH PM	10 TO 25	0 TO 12
LONG-DURATION SORTIE	EXTENSIVE IMPROVEMENT	90	EXTENSIVE IM-PROVEMENT WITH PM	15 TO 25	0 TO 12
FREE-FLYING UNMANNED	EXTENSIVE IM-PROVEMENT PM SUPPORTED	90+	NONE	25 TO 50	0 TO 20
FREE-FLYING MANNED	PM SUPPORTED	90+	NONE	25 TO 50	0 TO 20
SPACE PLATFORM OR SPACE CON-STRUCTION BASE SUPPORT	SPACE BASED CONFIGURATION	90+	NONE	250	0 TO 75

*REFERENCED DOCUMENTS DESCRIBE MODIFICATIONS FOR SPACELAB GROWTH. ATTACHMENT TO THE PM WILL BE THROUGH THE UNIVERSAL DOCKING RING.
**FOR TOTAL MISSION SUPPORT. VARIES ACCORDING TO THE GROWTH SCENARIO USED (SEE ERNO STUDY).

- Mission flexibility and long range usefulness of the Teleoperator can be implemented by addition to the basic vehicle of readily installable/removeable kits. These kits will add the following capability to the Teleoperator:

Manipulator	–	Enables the Teleoperator to assist in docking operations-Power Module to Orbiter, other payloads, and large space structures
	–	Assist the astronaut in EVA operations, planned or contingency
Hydrazine Propulsion	–	Provides an increased performance, multiple reuse, and optional propellant dump capability
Satellite Capture Mechanisms and Services	–	Provides the Teleoperator the capability to capture, maintain, and repair, a degraded or failed satellite to return it to operational status
EPDS * Orbital Storage Kit	–	Provides a solar array/battery system that will provide power to the Teleoperator when it is in on-orbit storage mode (18 months maximum)
Steerable High-Gain Antenna	–	Ground and TDRSS communication capability
Servicer	–	Provide satellite-peculiar services

- If use of the Teleoperator is planned in conjunction with Orbiter/Power Module operations, an ideal orbital storage mode for Teleoperator is attached to the Power Module. In that event several of the above add-on kits are not required.

* Electrical Power Distribution System

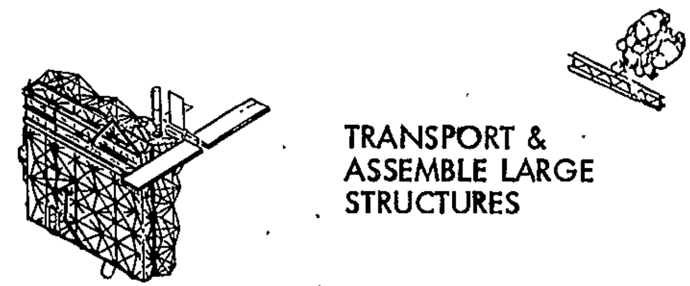
TELEOPERATOR GROWTH OPTIONS

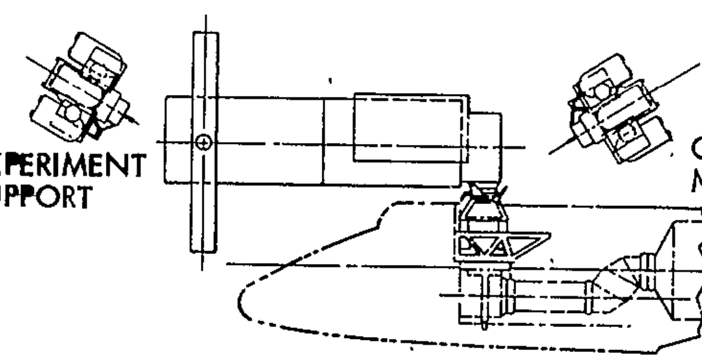
POTENTIAL MISSIONS

- LARGE STRUCTURE ASSEMBLY & TRANSPORT
- EMERGENCY PAYLOAD REPAIRS
- EXPERIMENT SUPPORT
- PAYLOAD RETRIEVAL AT HIGH ORBITS
- RETRIEVAL OF UNSTABLE OBJECTS OR SPACE DEBRIS
- EVA SUPPORT
- HAZARDOUS MATERIAL HANDLING
- DRAG MAKEUP/ALTITUDE INCREASE
- SPACECRAFT MAINTENANCE
- PAYLOAD DELIVERY
- DESATURATE CMGs

SUBSYSTEM GROWTH OPTIONS

- MANIPULATOR KIT
- INCREASED CAPABILITY HYDRAZINE PROPULSION KIT
- SATELLITE CAPTURE MECHANISMS
- EPDS ORBITAL STORAGE KIT
- STEERABLE HIGH GAIN ANTENNA KIT
- SPACECRAFT-PECULIAR SERVICES





- The Payload Docking Module (PDM) concept discussed previously appears to have a variety of applications with other elements of the Space Transportation System (STS). Its basic function is to interconnect the elements. It also provides the capability to assemble any orthogonal multiunit space platform configuration.

- In accomplishing these functions, it is evident that the standardized subelements described in the chart will be desired. Such subelements are likely to be needed with other elements of the STS, even when the PDM is not required. The benefits of standardization and multipurpose utility may be achieved if these subelements are developed as part of a "Payload Docking Module Element System," rather than allowing development of them as peculiarized items designed to serve the needs of a single element.

PAYLOAD DOCKING MODULE GROWTH POTENTIAL

- ROTATABLE INTERFACE ADAPTER

  ALLOWS CLOCKING OF MATING ELEMENTS AND FACILITATES DOCKING AND DEMATING.

- EMERGENCY ECLS PACK

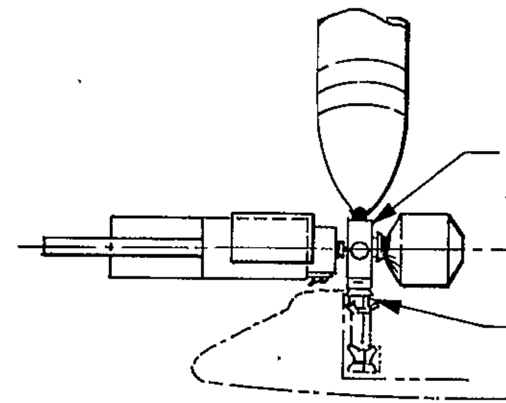
  PROVIDES AN ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS) MODULE ENABLING USE OF INTER-FACE MODULE AS SHORT-TERM LIFE-RAFT.

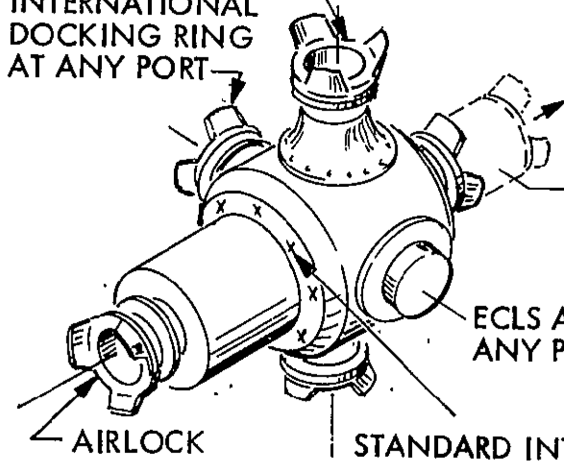
- AIRLOCK CHAMBER

  PROVIDES AIRLOCK FOR EVA OR IVA OPERATIONS WITH ANY ELEMENT COM COMBINATION.

- CYLINDRICAL ADD-ON SEGMENTS

  PROVIDES ADDITIONAL PRESSURIZED VOLUME AND INCREASED CLEARANCE BETWEEN MATING ELEMENTS.



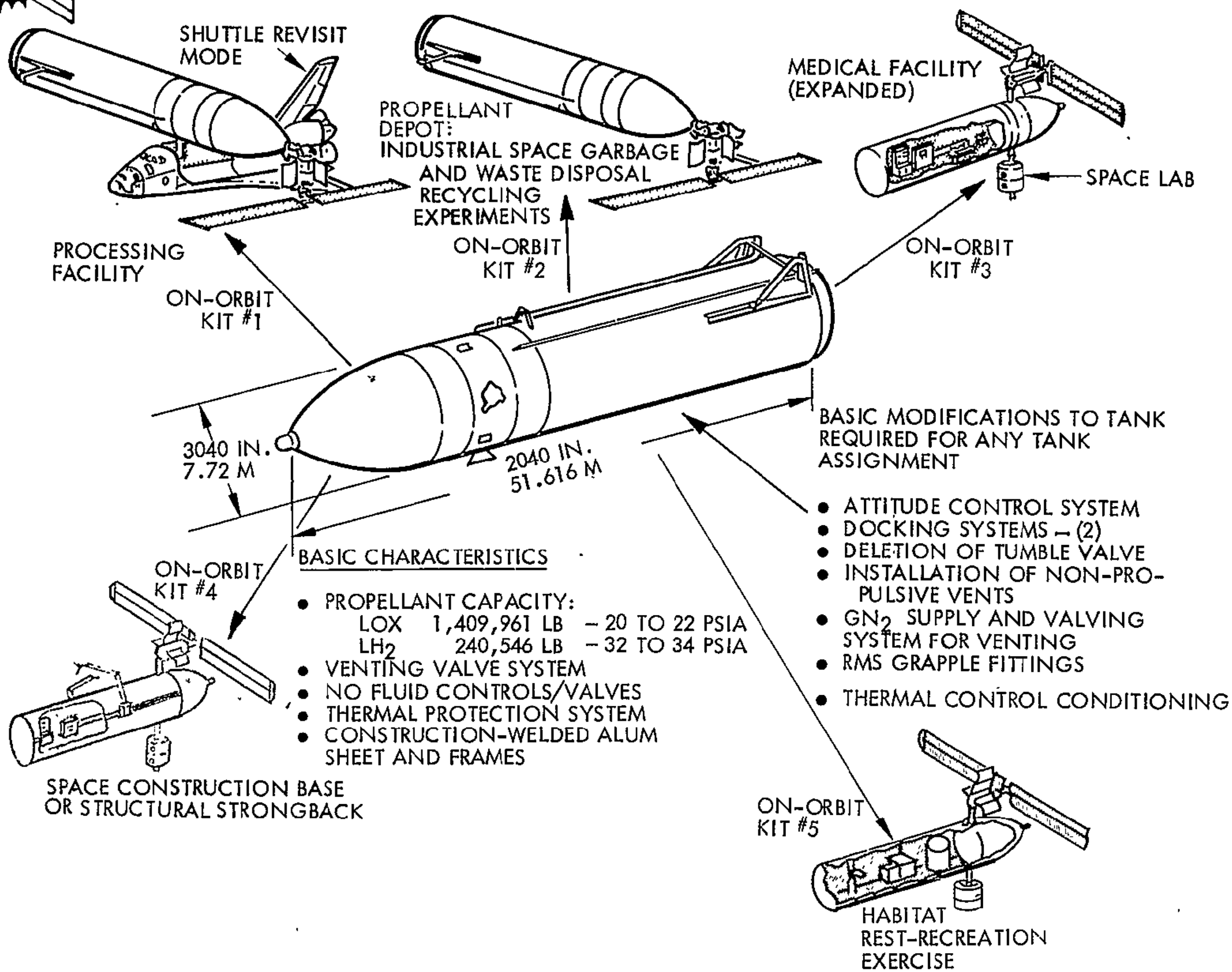


- The External Tank is the propellant (drop) tank for the Space Shuttle Orbiter. The tank is significant as a support element in that it could be modified to provide a large volume orbital work station. The dimensions and construction (pressure-tight aluminum cylinder) of the external tank make this item an attractive candidate for assignments after separation from the Orbiter. By docking the tank structure with other support elements, by means of the Payload Docking Module, a total compartment volume (LOX and LH_2) of about 80,000 ft^3 is potentially available for mission use.

- Basic modifications to each tank before launch would be required to prepare the tank for its further assignment. Deletion of the tumbling valve and the addition of subsystems for attitude control; docking and entry; purging, venting and grappling; by Orbiter RMS or Teleoperator would be accomplished prior to launch. A waiver to delete the range safety system would be required.

- On-orbit kits, tailored for each assignment, would be prefabricated and delivered by Shuttle to the orbiting External Tank. Astronaut activity in the refitting of these tanks and throughout its assigned use could be of both EVA and IVA nature.

EXTERNAL TANK — MODIFIED FOR FUTURE GROWTH



MISSION SUPPORT REQUIREMENTS

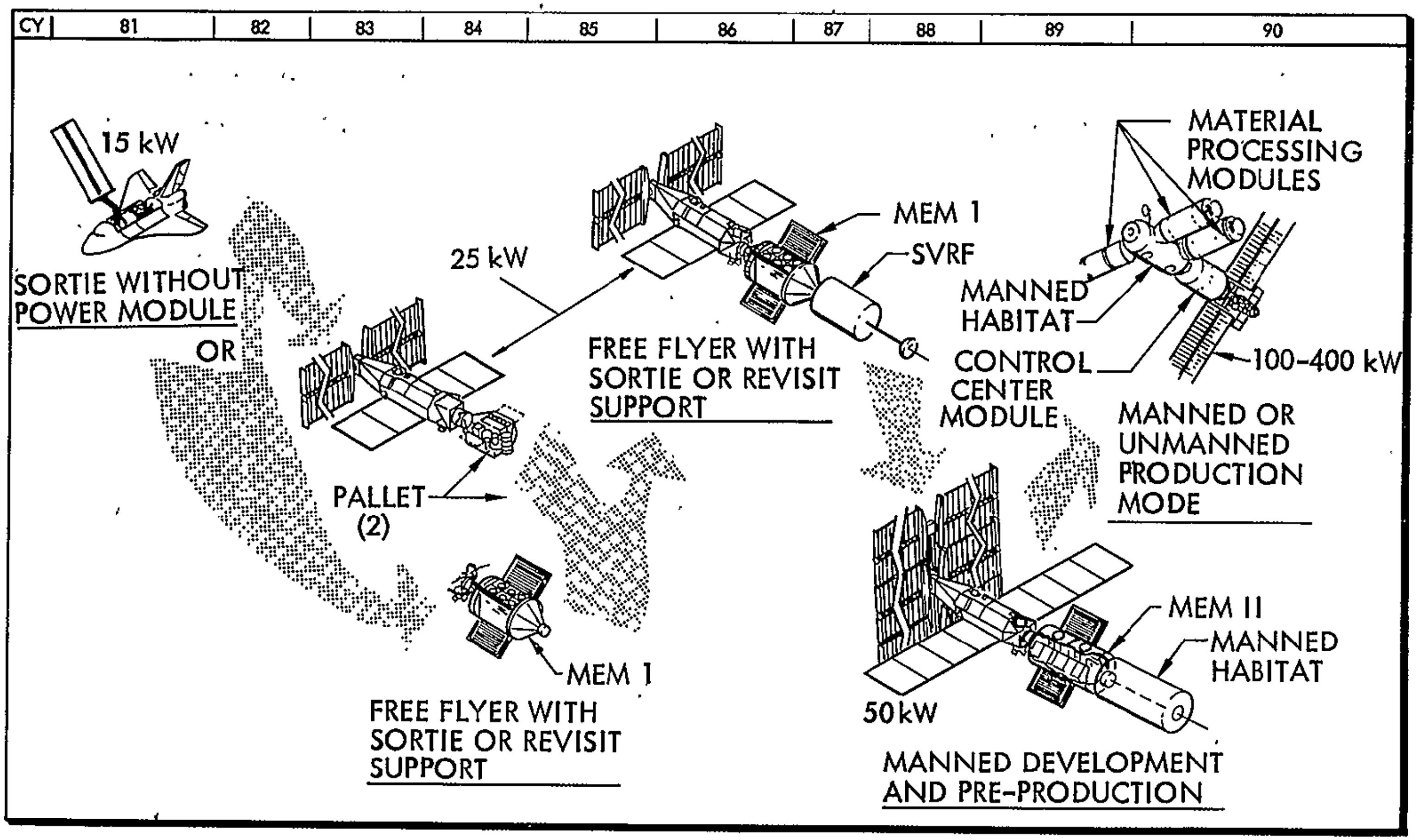
- DESIRED MISSION SCENARIOS
- SUMMARY PAYLOAD POWER REQUIREMENTS
- PM GROWTH SCENARIO TO MEET DESIRED REQUIREMENTS

- In the early years of 1981 to 1982, material processing will be supported by the 15 kW PEP. Planned technology development exceeds the power demand beyond PEP capability. If available, a 25 kW PM can be utilized as early as 1983 thru 1986.

- Higher production development techniques, both automated and man involvement in the late 1980s, will boost the demand upward in evolutionary steps from 50 kW to nearly 400 kW.

- All material processing operations will be in LEO and the shuttle will provide sortie support to both unmanned and manned free-flyers.

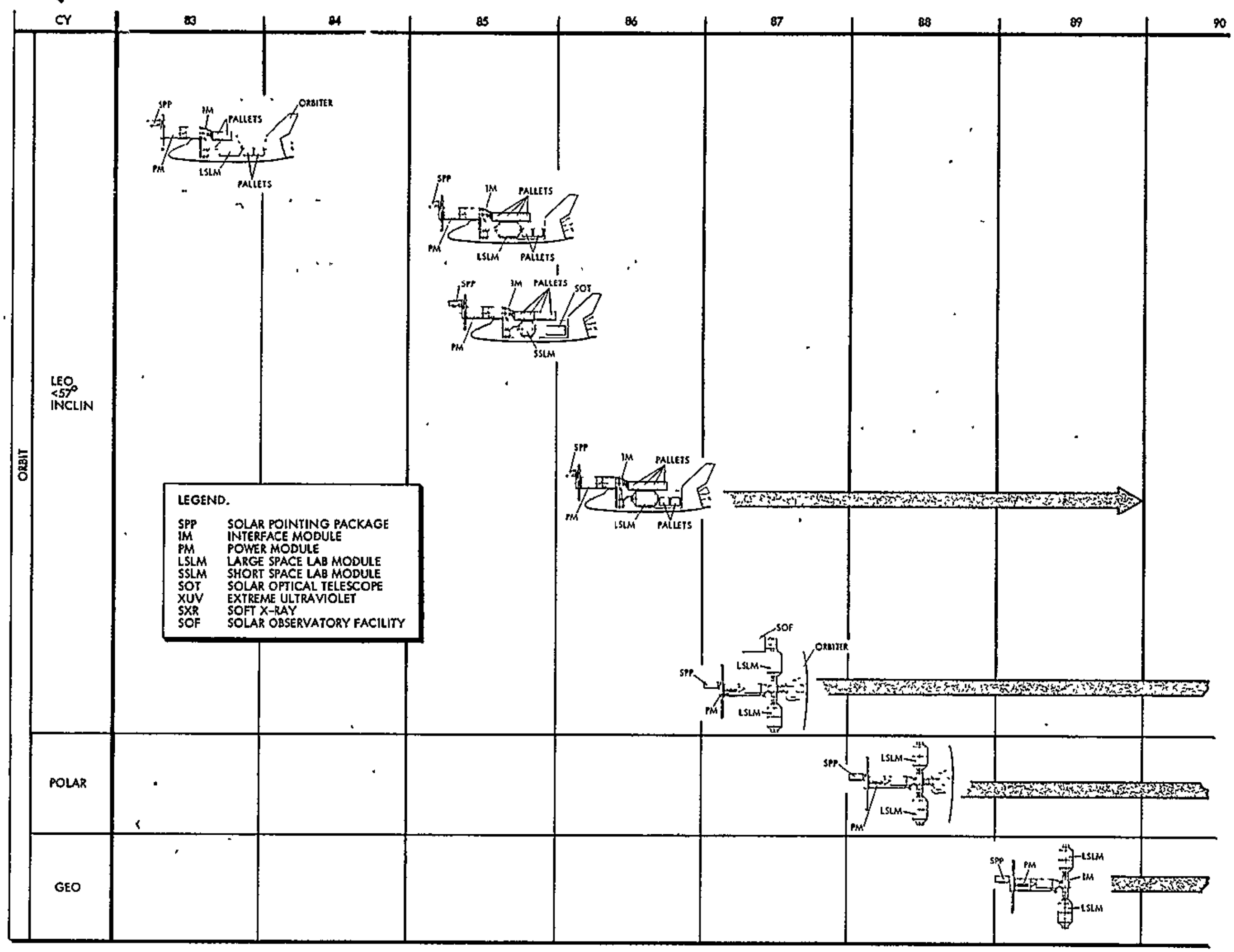
MATERIAL PROCESSING–DESIRED SCENARIO



- This chart shows the early utilization of a 25 and 50 kW PM permitting the scientific community to study the solar-earth system and conduct tests and experiments with large (3.6 M x 7 M) solar optical telescopes.

- 100 kW in 1986 would give man an early opportunity to live and work in space. This preparation could be crucial to a well coordinated scientific effort in polar and GEO prior to entering the solar cycle (1990 to 1991).

STO—DESIRED SCENARIO

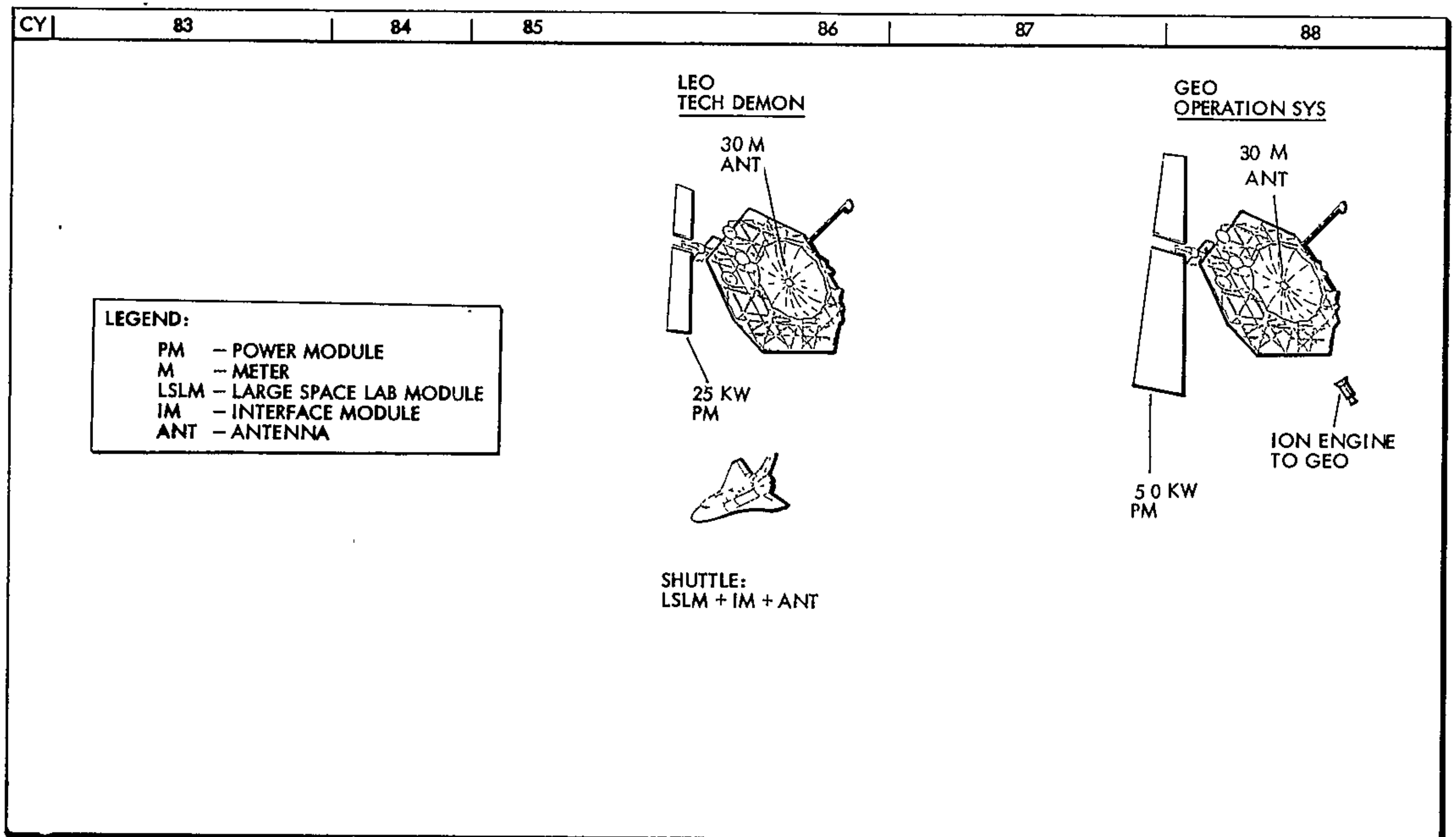


- The next two charts are public service representatives of the need for 50 to 200 kW class Solar power systems in GEO.

- These public service representatives are tested and operationally demonstrated in LEO then boosted to GEO for final operations.

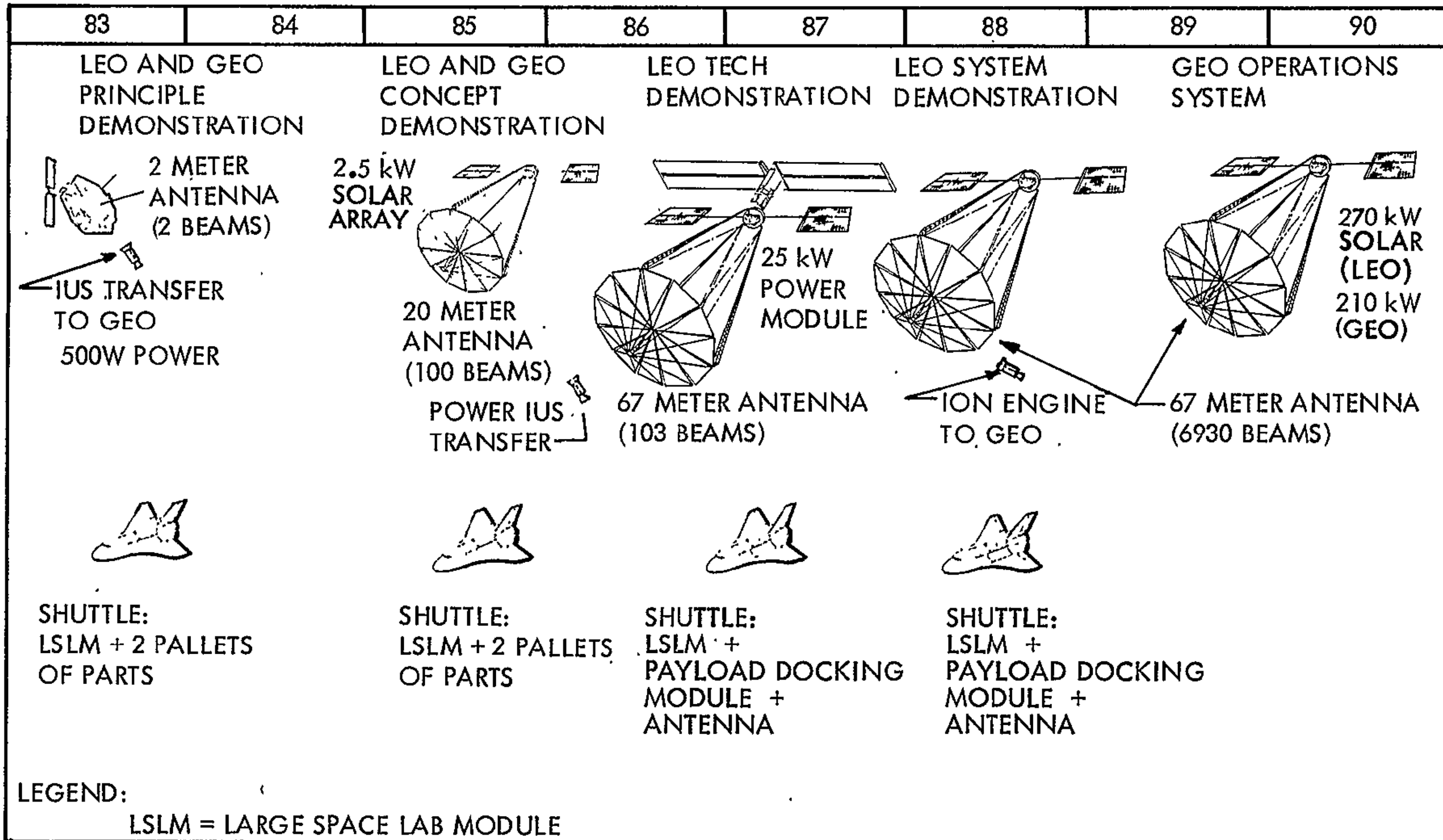
- The type of total system activities involved clearly reflects that the highest demand for large dedicated Solar power sources will occur in the 1989 to 1990 time period.

PUBLIC SERVICES REPRESENTATIVE SCENARIO — DESIRED



PUBLIC SERVICES REPRESENTATIVE — DESIRED

COMMUNICATION SATELLITE



C-3

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This chart delineates payload and key space support power requirements by orbit and time. The power needs for any given year are shown by cumulative totals. These power needs are met by PEP/Sortie and/or 1 to 4 Power Modules of five different sizes. Where power requirements exceeded reasonable evolutionary Power Module development (size and quantity) time sharing, where practical, was used as a restraint to permit highest mission potential.

SUMMARY PAYLOAD POWER REQUIREMENTS (kW)

DISCIPLINE	28.5° ORBIT								50° TO 57° ORBIT							
	83	84	85	86	87	88	89	90	83	84	85	86	87	88	89	90
MATERIAL PROCESSING	25A	25A	25A	25A	25A	33A	33A	133A	*25A	25A	25A	25	25	50	100	100
SOLAR TERRESTRIAL OBSERVATORY									10P	15P	20A	20	23	28	28	28
PUBLIC SERVICE				*15B		*20C						15		20		
SPACE SCIENCE	2P	2P	5P	*10B	*10B	10B	10B	17A	2A	*2A	2P	*15	15	*15	15	15
LIFE SCIENCE	5P	5P	5P	*7B	17B	17B	17B	*40B								
EARTH OBSERVATION									5P	*5A	10P	*10	10	10	10	10
PACE CONSTRUCTION BASE	5P	5P	5P													
CONSTRUCTION BASE				*40C	*40C	*75C	*75C	*75B								
HABITAT				10B 10C	10B 10C	10A 10B 10C	10A 10B 10C	20B				10	10	10	10	10
DEPOT								*100B								
SPACECRAFT MAINTENANCE				*10C	*30C	*35C	*35C	*35B								
WORKSHOP				7B 7C	7B 7C	7A 7B 7C	17A 7B 7C	7B				7	7	7	7	7
ORBITER				14B 14C	14B 14C	14A 14B 14C	14A 14B 14C	14B				14	14	14	14	14
PEP/SORTIE	12	12	15						15	15	12					
PM #A	25	25	25	25	25	50	50	150	25	25	50	100	100	100	100	100
PM #B				50	50	50	50	150								
PM #C				50	100	100	100									
PM #D																

SYMBOLS: P = TIME SHARED PEP/SORTIE
* = TIME SHARED TO CORRESPOND TO PM OUTPUT

SUMMARY PAYLOAD POWER REQUIREMENTS (kW)

DISCIPLINE	90° ORBIT								GEO							
	83	84	85	86	87	88	89	90	83	84	85	86	87	88	89	90
MATERIAL PROCESSING																
SOLAR TERRESTRIAL OBSERVATORY						47	47	47								50D
PUBLIC SERVICE												*15	*20A *10B	*30A *50B	*30A *50B 210C	*30A *50B 210C
SPACE SCIENCE	5P	5P	5P	5P				*15				*10	*10A *10B	*10A *10B	*10A *10B	*10A *10B
LIFE SCIENCE	10P	10P	10P	10P												
EARTH OBSERVATION			*20A	*20A	*25	*30	*30	*30				*10	*15B	*15A	*15A	*15A
SPACE CONSTRUCTION																
CONSTRUCTION BASE																
HABITAT						10	10	10								10D
DEPOT																50D
SPACECRAFT MAINTENANCE																
WORKSHOP						7	7	7								7D
ORBITER			14	14	14	14	14	14								
PEP/SORTIE	15	15	15	15												
PM #A			25	25	25	100	100	100				25	25	50	50	50
PM #B													25	50	50	50
PM #C															200	200
PM #D																100

SYMBOLS: P = TIME SHARED PEP/SORTIE
* = TIME SHARED TO CORRESPOND TO PM OUTPUT

- The composite mission requirements are tabularized in the next two charts in a format that shows the expanding requirements with time.

- It includes all of the primary Power Module requirements and identifies those support elements necessary to fulfill the mission needs.

COMPOSITE PAYLOAD REQUIREMENTS

	DESIRED																	
	POWER MODULE							SUPPORT ELEMENTS										
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
28.5° ORBIT																		
1983-1985	25	11	±0.5°	365	12	0.03	1	X	-	X	-	-	-	-	-	-	-	-
1986-1987	175	77	±0.5°	365	24	.075	4	-	X	X	X	X	X	X	X	-	X	X
1988-1989	200	88	±0.5°	365	32	0.1	3	-	X	X	X	X	X	X	X	-	X	X
1990	300	132	±0.5°	365	25	0.1	2	-	X	X	X	X	X	X	X	X	X	X
50-57° ORBIT																		
1983-1985	50	22	30$\bar{S}$	365	22	15	2	X	-	X	-	-	-	-	-	-	-	-
1986-1988	100	44	30$\bar{S}$	365	36	20	1	-	X	X	X	X	-	-	-	-	-	X
1989-1990	100	44	30$\bar{S}$	365	41	25	1	-	X	X	X	X	-	X	-	-	-	X

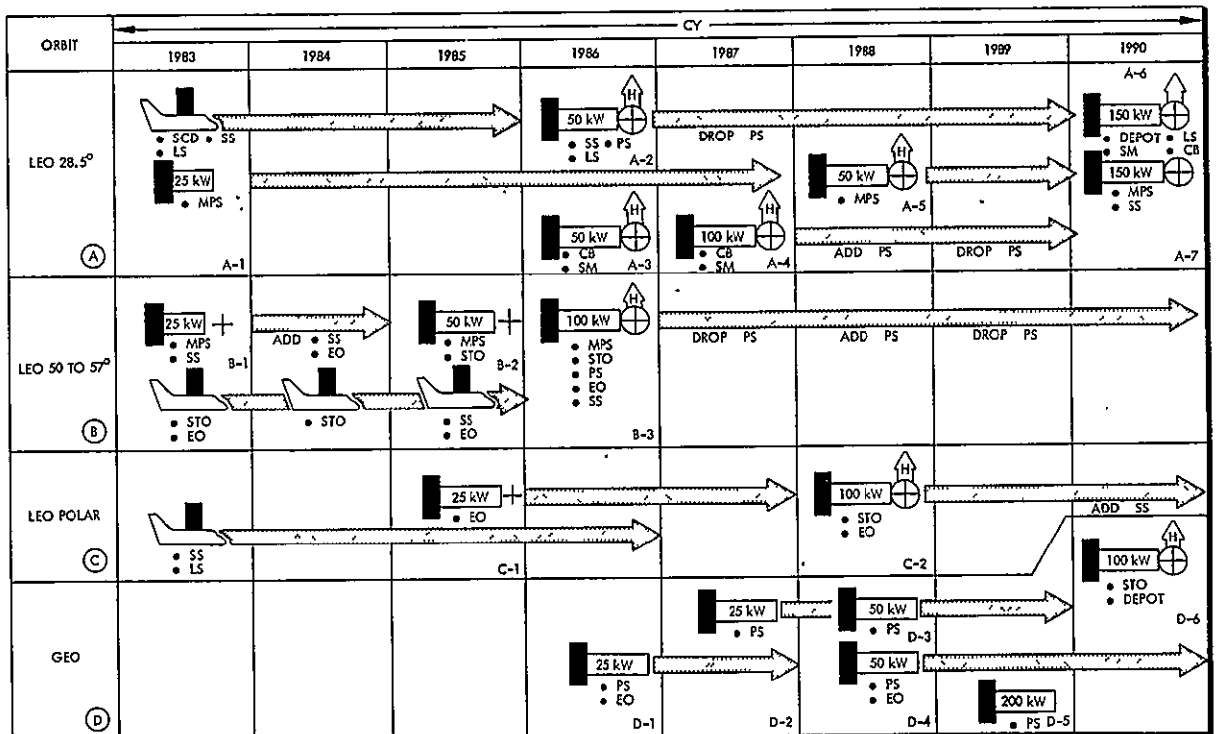
COMPOSITE PAYLOAD REQUIREMENTS

	DESIRED																	
	POWER MODULE						SUPPORT ELEMENTS											
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
90° ORBIT																		
1985-1987	25	11	$30\bar{S}$	365	12	10	1	X	-	X	-	-	-	-	-	-	-	-
1988-1990	100	44	$30\bar{S}$	365	25	25	1	-	X	X	X	X	-	-	-	-	-	-
GEO ORBIT																		
1983-1986	25	11	$30\bar{S}$	365	12	1	1	X	-	X	-	-	-	-	-	-	-	-
1987-1988	100	44	$30\bar{S}$	365	16	5	4	X	-	-	-	-	-	X	-	-	-	X
1989	300	132	$30\bar{S}$	365	25	12	3	X	-	-	-	X	-	X	X	-	-	X
1990	400	176	$30\bar{S}$	365	35	25	4	-	X	X	X	X	-	X	X	-	-	X

- This chart represents maximum Power Module Requirements for each orbit location and time period between 1983 and 1990.

- The requirements for the different sizes and quantities of Power Modules are based on assumed payload availability (without technology development encumberances or cost constraints) and work from Part I.

POWER MODULE GROWTH SCENARIO (MAXIMUM REQUIREMENTS CASE)



	POWER MODULE
+	DOCKING MODULE – UNPRESS
	DOCKING/WORKSHOP MODULE – PRESS
15 kW	SORTIE ONLY – PEP AVAILABLE ALL YEARS
	MANNED HABITAT – FREE-FLYER MODE
	REQUIRES PAYLOAD STABILIZATION KIT
	25 kW DERIVATIVE HARDWARE
SK	SKYLAB
IM	SKYLAB INTERFACE MODULE

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  - GEO PLATFORM
  - OTHERS
- SCD SPACE CONSTRUCTION DEMO
- LS LIFE SCIENCE

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CANDIDATE COMPOSITE PAYLOAD SUPPORT SYSTEM EVOLUTIONS

- The primary objective of this study is to derive candidate evolutionary systems by logical growth stages that will support integrated (mixed discipline) payloads at optional levels of capabilities. From the mission requirements studies it was immediately obvious that all mission requirements could not be met simultaneously within a reasonable budget. Therefore, sharing resources and program stretchout are inevitable for most disciplines.

- In all cases the PM is assumed to become available in 1983. The Skylab reuse studies assumes that the earliest PM docking takes place in 1984.

- The PM composite requirement scenarios were constructed for minimum, nominal, and ambitious program levels based on judgments of the allowable hardware buildup (cost consideration) traded against the mission requirements identified in Part I. The next six page options represent the PM growth scenarios from 1983 to 1991. The mission requirements are satisfied in the four major orbit locations, 28.5°, 50° to 57°, Polar, and GEO. Scenarios were developed for evaluating the conditions without the Skylab and with a reusable Skylab.

- It is assumed that the Orbiter will have PEP to support sortie missions of various durations in each of the three primary LEO orbits and will most likely be starting space construction demonstrations early in the 28.5° orbit. The first PM is required in 57° to support early sortie and free-flyer missions with STO, MPS, and SS. The MPS would move to 28.5° orbit as soon as it can have its own dedicated PM. Extended use of the PM is a goal, particularly for the minimum scenarios.

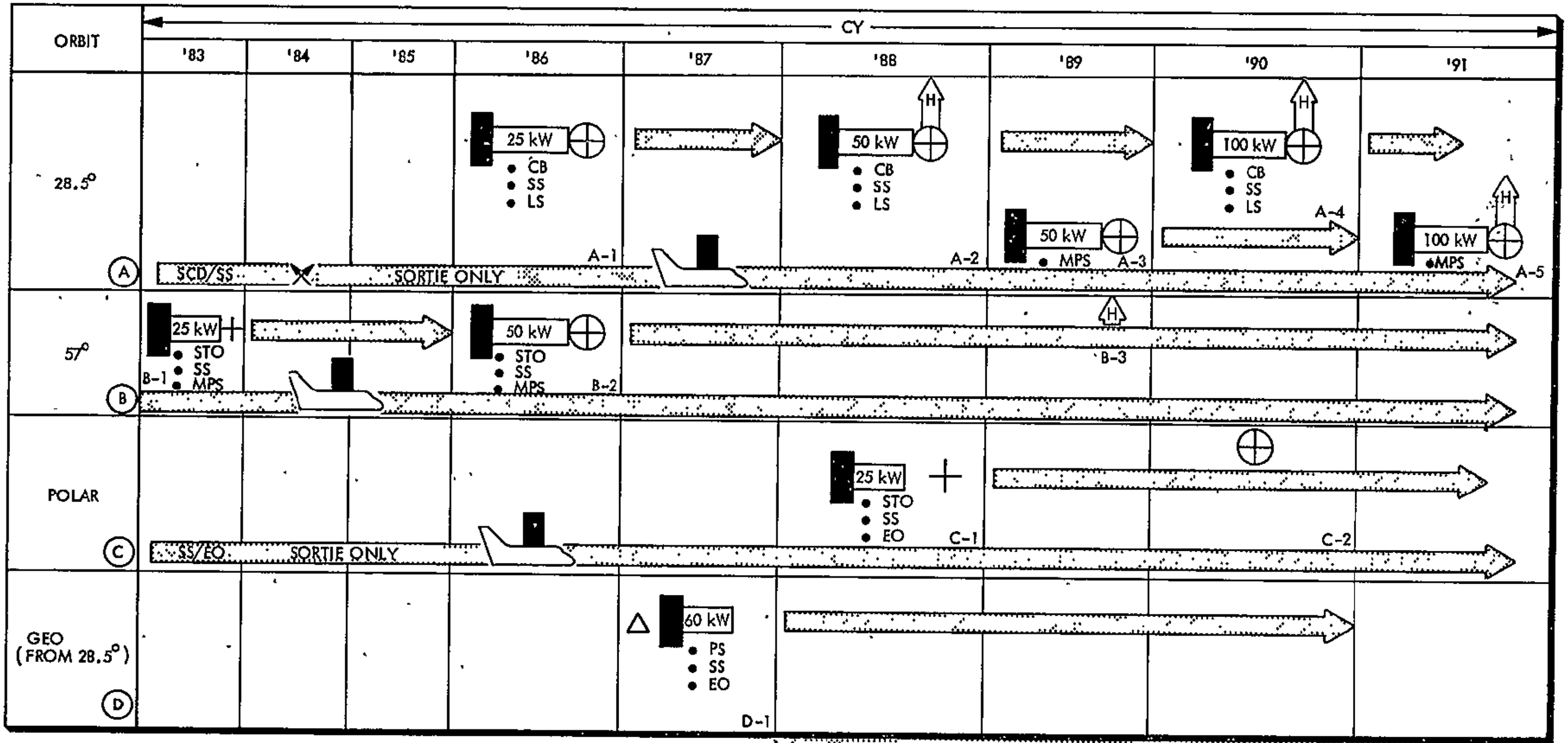
- The Power Module composite requirements scenarios were constructed for minimum, nominal, and ambitious program levels based on judgments as to the allowable hardware buildup (cost consideration) traded against the mission requirements identified in Part I. It was immediately obvious that all mission requirements could not be met simultaneously within a reasonable budget. Therefore, sharing resource and program stretchouts are inevitable for most disciplines.

- The next six pages (six scenarios, two each nominal, minimum and ambitious) represent the (Don Saxton, COR) coordinated 1982 to 1990 scenarios of Power Module evolution in four orbit locations, 28.5^{o}, 50^{o}, and 57^{o}, polar, and GEO.

- Some assumptions and observations are:

  - The first Power Module will be available in 1983 for the 57^{o} or 50^{o} orbits.
  - Power Module docking with the Skylab will be achievable by 1984.
  - MPS does not require construction activity until a dedicated Power Module is available in 28.5^{o}.
  - Extended use of Power Modules is a goal, particularly for the minimum scenarios.
  - PEP is available for Shuttle Sortie from 1983 to 1990 in all LEO cases.
  - Power Module in GEO is a derivative of the basic 25 kW Power Module.

PROGRAM SCENARIO I
(NOMINAL – NO SKYLAB)



	POWER MODULE
+	DOCKING MODULE – UNPRESS
⊕	DOCKING/WORKSHOP MODULE – PRESS
15 kW	SORTIE ONLY – PEP AVAILABLE ALL YEARS
H	MANNED HABITAT – FREE-FLYER MODE
	REQUIRES PAYLOAD STABILIZATION KIT
△	25 kW DERIVATIVE HARDWARE
SK	SKYLAB

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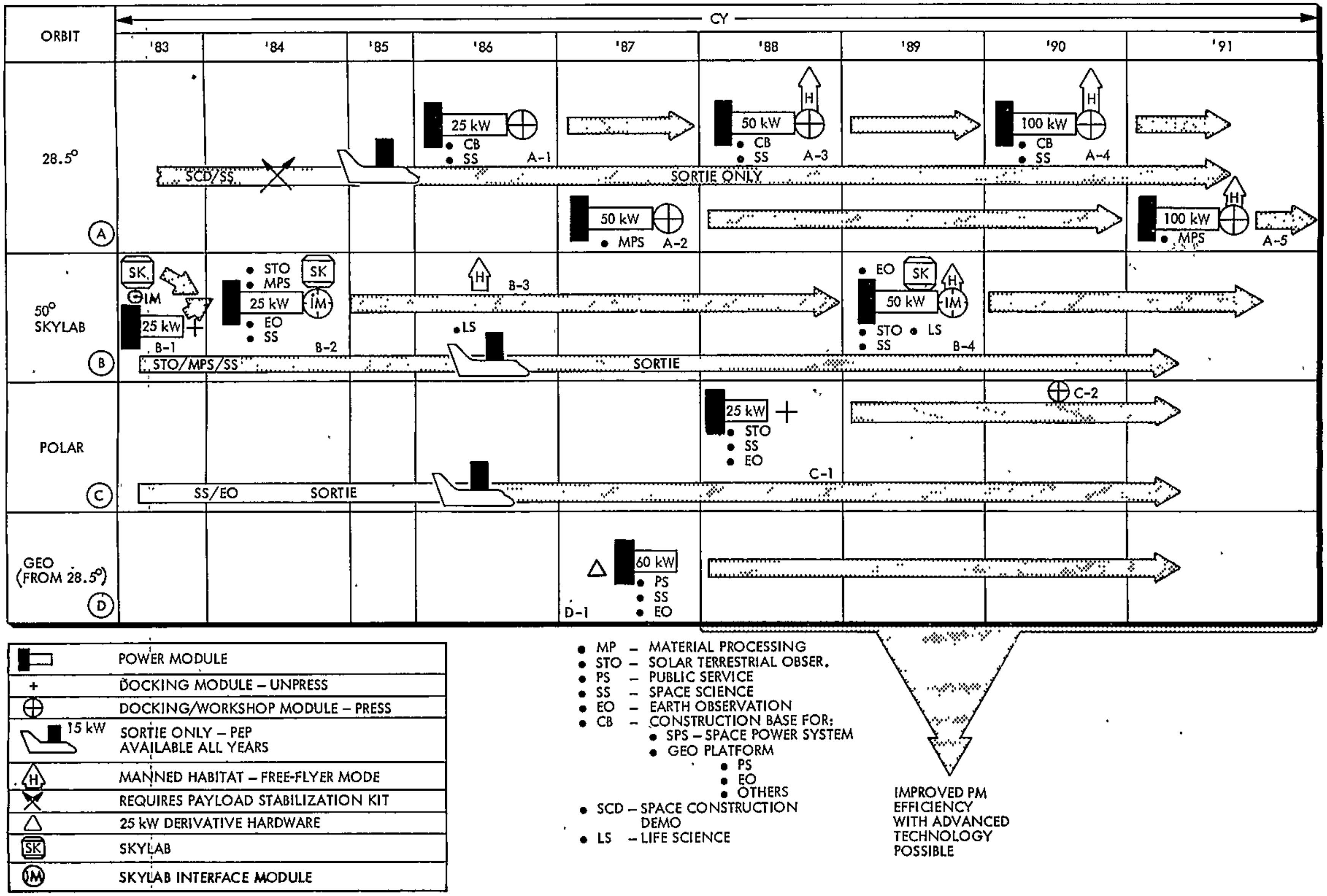
  - GEO PLATFORM
    - PS
    - EO
    - OTHERS
- SCD – SPACE CONSTRUCTION DEMO
- LS – LIFE SCIENCE

IMPROVED PM EFFICIENCY WITH ADVANCED TECHNOLOGY POSSIBLE

PROGRAM SCENARIO II (NOMINAL – WITH SKYLAB)



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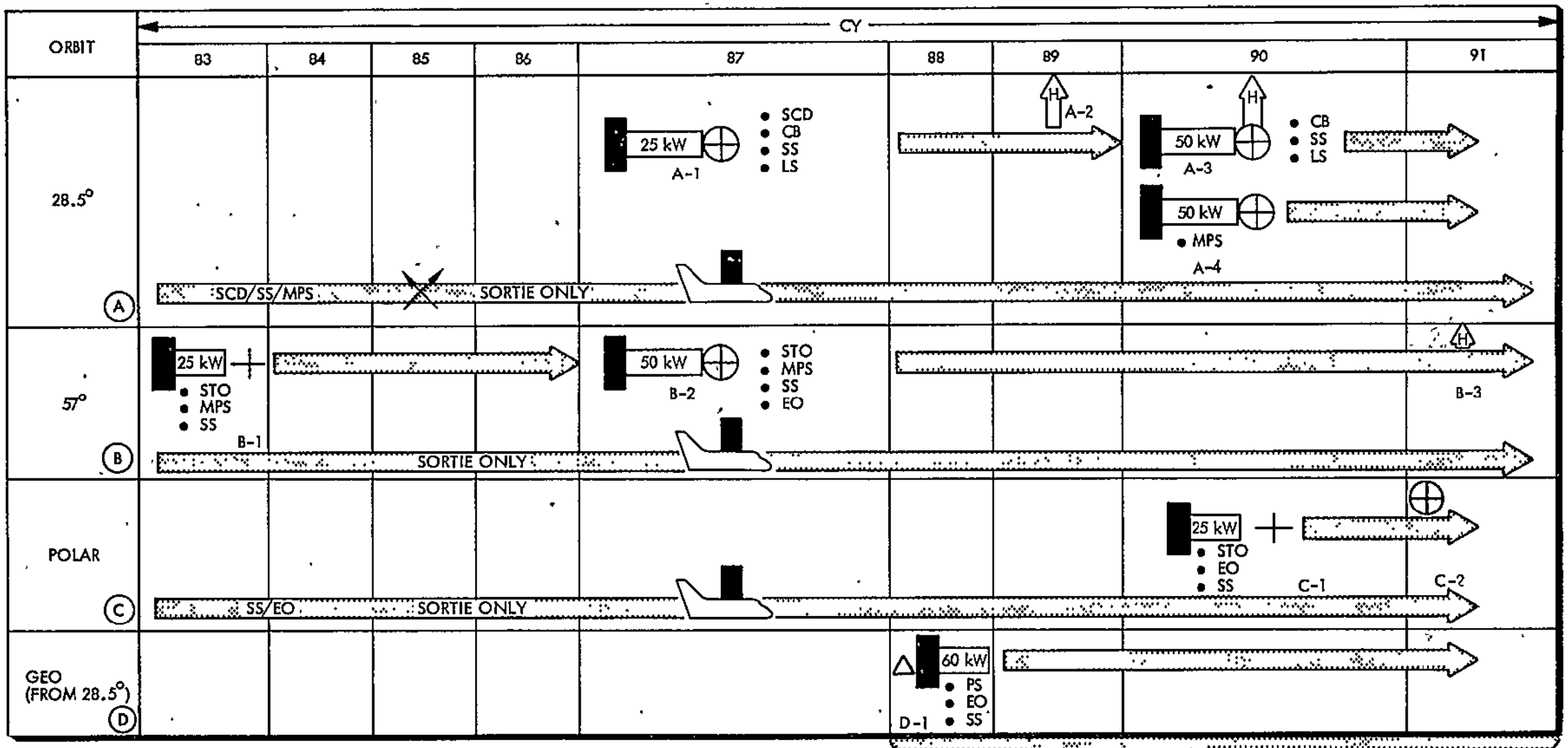
IMPROVED PM EFFICIENCY WITH ADVANCED TECHNOLOGY POSSIBLE

PROGRAM SCENARIO III (MINIMUM-NO SKYLAB)



	POWER MODULE
	DOCKING MODULE – UNPRESS
	DOCKING/WORKSHOP MODULE – PRESS
15 kW	SORTIE ONLY – PEP AVAILABLE ALL YEARS
H	MANNED HABITAT – FREE-FLYER MODE
	REQUIRES PAYLOAD STABILIZATION KIT
	25 kW DERIVATIVE HARDWARE
SK	SKYLAB

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IMPROVED PM EFFICIENCY WITH ADVANCED TECHNOLOGY POSSIBLE

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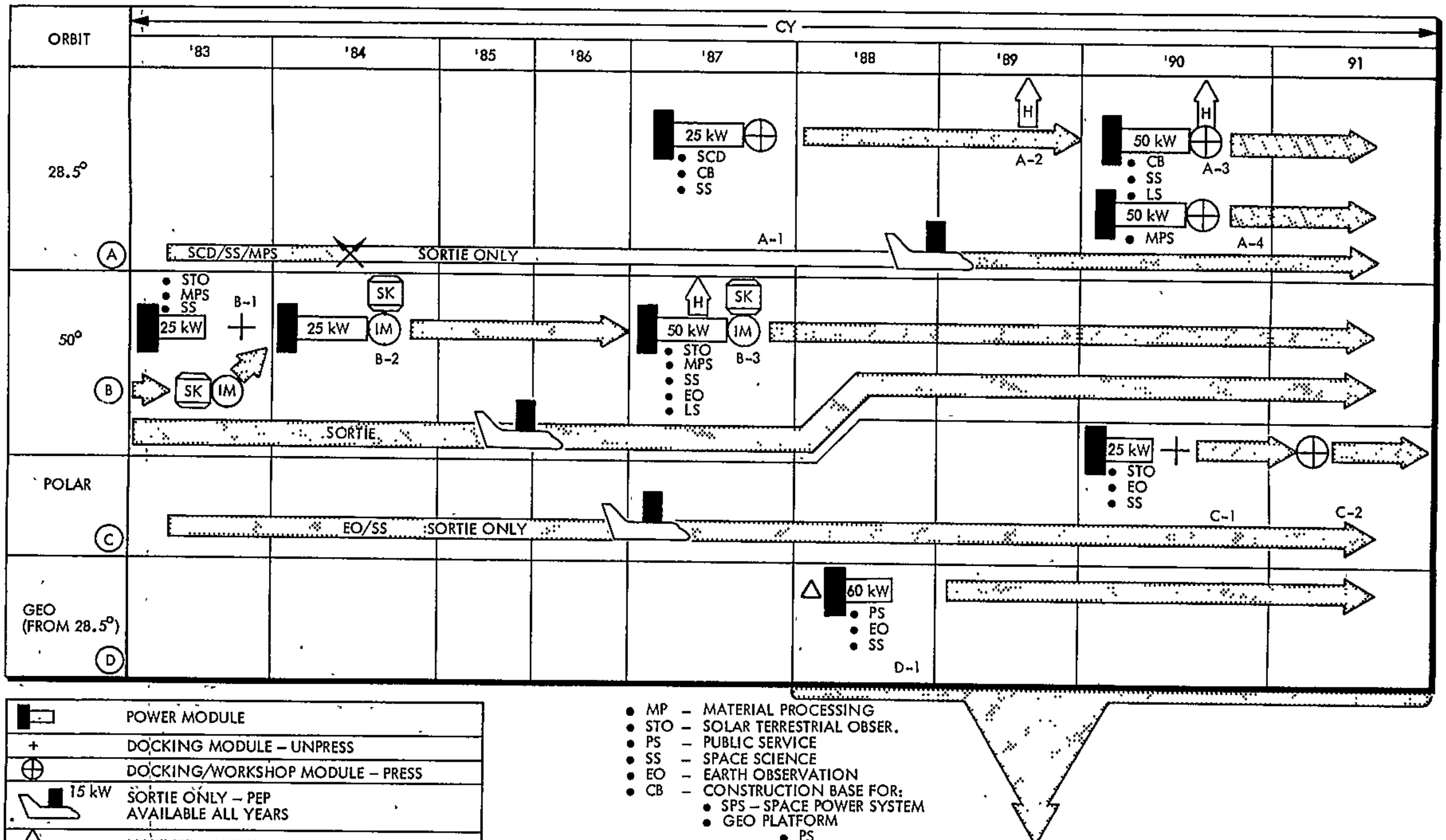
PROGRAM SCENARIO IV (MINIMUM – WITH SKYLAB)



	POWER MODULE
+	DOCKING MODULE – UNPRESS
⊕	DOCKING/WORKSHOP MODULE – PRESS
15 kW	SORTIE ONLY – PEP AVAILABLE ALL YEARS
H	MANNED HABITAT – FREE-FLYER MODE
	REQUIRES PAYLOAD STABILIZATION KIT
△	25 kW DERIVATIVE HARDWARE
SK	SKYLAB
IM	SKYLAB INTERFACE MODULE

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    - PS
    - EO
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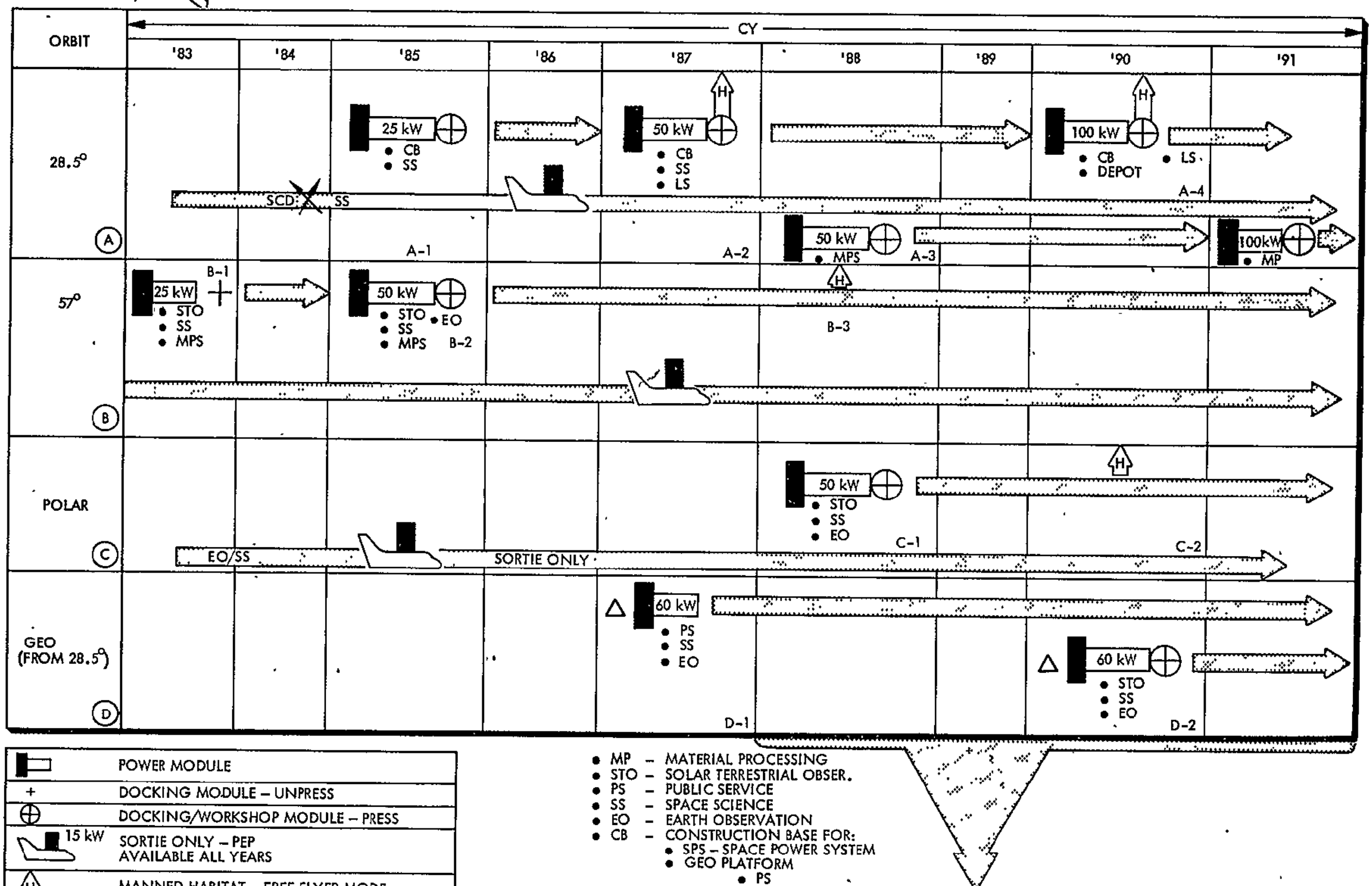
IMPROVED PM EFFICIENCY WITH ADVANCED TECHNOLOGY POSSIBLE

PROGRAM SCENARIO V
(AMBITIOUS WITHOUT SKYLAB)



	POWER MODULE
+	DOCKING MODULE – UNPRESS
⊕	DOCKING/WORKSHOP MODULE – PRESS
15 kW	SORTIE ONLY – PEP AVAILABLE ALL YEARS
H	MANNED HABITAT – FREE-FLYER MODE
	REQUIRES PAYLOAD STABILIZATION KIT
△	25 kW DERIVATIVE HARDWARE
SK	SKYLAB

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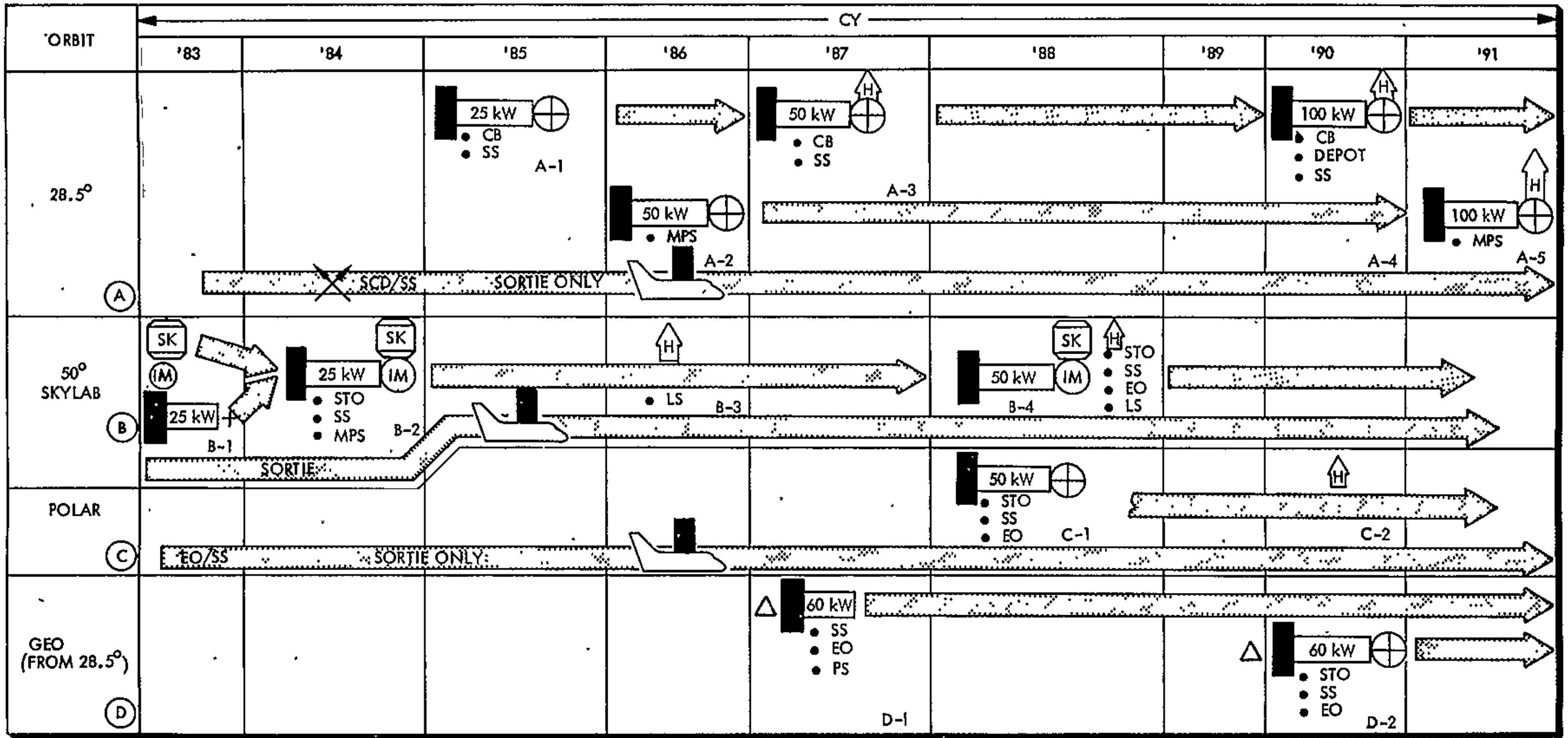
IMPROVED PM EFFICIENCY WITH ADVANCED TECHNOLOGY POSSIBLE

PROGRAM SCENARIO VI
(AMBITIOUS-WITH SKYLAB



- POWER MODULE
- \+ DOCKING MODULE – UNPRESS
- DOCKING/WORKSHOP MODULE – PRESS
- 15 kW SORTIE ONLY – PEP AVAILABLE ALL YEARS
- H MANNED HABITAT – FREE-FLYER MODE
- REQUIRES PAYLOAD STABILIZATION KIT
- 25 kW DERIVATIVE HARDWARE
- SK SKYLAB
- IM **SKYLAB INTERFACE MODULE**

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IMPROVED PM EFFICIENCY WITH ADVANCED TECHNOLOGY POSSIBLE

GENERAL

Items of importance and observation about the data on the next 15 charts on growth system capability analysis are:

- There are six scenarios depicted and each reflects the mission in four orbits, 28.5°, 50°, and 57° polar, and GEO between 1983 and 1990.
- The first three scenarios are emphasized in this analysis. They are: Nominal Scenario I – No Skylab; Nominal Scenario II – With Skylab; and Minimum Scenario III – No Skylab.
- Sortie missions shown in the scenarios were not considered in this analysis.
- In cases where the payloads power requirements in the scenarios exceed the Power Module configuration output, available power will be time-shared.
- Each configuration change, i.e., Power Module size or other, is represented by a letter and dash number designation as an aid in following the activities.
- The analyses data are organized by orbit groups, consecutively and separately, 28.5°, 50°, and 57° combined, polar, and GEO with corresponding text.

- This analysis represents Power Module and support elements in terms of composite system capability for 28.5° orbit in various increments of time from 1983 to 1990 and applicable to the Power Module or configuration change.

- In the early years, 1983 to 1985, the Power Module will not be used. Composite system capabilities are met by the Orbiter/PEP Sortie except for the GEO case.

- Of the three scenarios analyzed, Scenario II is to be emphasized. It represents the best growth and development picture in terms of payload mix, configuration changes, and Power Module size, 25 to 100 kW by 1990. The 28.5° orbit also represents the orbit where payload development and testing originates in preparation for launch and GEO operation.

GROWTH SYSTEM CAPABILITY ANALYSIS
28.5° ORBIT

1986 SCENARIO

	POWER MODULE						SUPPORT ELEMENTS											
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION °	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	175	77	±0.5	365	24	.075	4	-	X	X	X	X	X	X	X	-	X	X
NOMINAL A-1 SCENARIO I	25	11	±0.5°	365	12	.035	1	-	X	X	X	-	-	-	-	-	-	X
NOMINAL A-1 SCENARIO II	25	11	±0.5°	365	8	.025	1	-	X	X	X	-	-	-	-	-	-	X
NOMINAL A-1 SCENARIO III	N/C																	

N/C – NO CONFIGURATION

GROWTH SYSTEM CAPABILITY ANALYSIS
28.5° ORBIT

1987 SCENARIO

	POWER MODULE						SUPPORT ELEMENTS											
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION°	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION
COMPOSITE PAYLOAD REQUIREMENTS	175	77	±0.5	365	24	.075	4	–	X	X	X	X	X	X	X	X	X	X
NOMINAL A-1 SCENARIO I	25	11	±0.5	365	12	035	1	-	X	X	X	-	-	-	-	X	-	X
NOMINAL A-1 SCENARIO II	25	11	±0.5	365	8	.025	1	-	X	X	X	-	-	-	-	X	-	X
MINIMUM A-1 SCENARIO III	25	11	±1.0	365	4	.012	1	-	X	X	X	-	-	-	-	X	-	X

GROWTH SYSTEM CAPABILITY ANALYSIS
28.5° ORBIT

1988 SCENARIO

	POWER MODULE						SUPPORT ELEMENTS											
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	200	88	±0.5	365	32	0.1	3	-	X	X	X	X	X	X	X	X	X	X
NOMINAL SCENARIO I	N/C																	
NOMINAL A-2 SCENARIO II	50	22	±0.5	365	4	.012	1	-	X	X	X	-	-	-	-	-	X	X
MINIMUM SCENARIO III	N/C																	

N/C – NO CONFIGURATION

GROWTH SYSTEM CAPABILITY ANALYSIS
28.5° ORBIT

1988 TO 1989 SCENARIOS

	POWER MODULE							SUPPORT ELEMENTS										
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION °	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	200	88	±0.5	365	32	0.1	3	-	X	X	X	X	X	X	X	-	X	X
NOMINAL A-2 SCENARIO I	50	22	±0.5	365	20	.06	1	-	X	X	X	X	-	-	-	-	-	X
NOMINAL A-3 SCENARIO II	50	22	±0.5	365	16	.048	1	-	X	X	X	X	-	-	-	-	-	X
MINIMUM A-1 SCENARIO III	25	1.1	±1.0	365	8	.024	1	-	X	X	X	X	-	-	-	-	-	X

GROWTH SYSTEM CAPABILITY ANALYSIS
28.5° ORBIT

1989 TO 1990 SCENARIOS

	POWER MODULE						SUPPORT ELEMENTS											
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION°	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	300	132	±0.5	365	25	0.1	2	-	X	X	X	-	-	-	-	-	-	-
NOMINAL A-3 SCENARIO I	50	22	±0.5°	365	4	.016	1	-	X	X	X	-	-	-	-	-	-	X
NOMINAL A-2 SCENARIO II	50	22	±0.5°	365	4	.016	1	-	X	X	X	-	-	-	-	-	-	X
MINIMUM A-3 SCENARIO III	N/C																	

N/C – NO CONFIGURATION

GROWTH SYSTEM CAPABILITY ANALYSIS
28.5° ORBIT

	POWER MODULE				DATA		SUPPORT ELEMENTS											
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION°	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	300	132	±0.5°	365	25	0.1	2	-	X	X	X	X	X	X	X	X	X	X
NOMINAL A-4 SCENARIO I	100	44	±0.5°	365	12	.050	1	-	X	X	X	X	-	-	-	-	-	X
NOMINAL A-4 SCENARIO II	100	44	±0.5°	365	8	.032	1	-	X	X	X	X	-	-	-	-	-	X
MINIMUM A-2 SCENARIO III	50	22	±1.0°	365	4	.016	1	-	X	X	X	X	-	-	-	-	-	X

GROWTH SYSTEM CAPABILITY ANALYSIS
28.5° ORBIT

1990 SCENARIO

	POWER MODULE				DATA		SUPPORT ELEMENTS											
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	300	132	±0.5°	365	25	0.1	2	-	X	X	X	-	-	-	-	-	-	X
NOMINAL SCENARIO I	N/C																	
NOMINAL SCENARIO II	N/C																	
MINIMUM A-3 SCENARIO III	50	22	±1.0°	365	2	.008	1	-	X	X	X	X	-	-	-	-	-	X

N/C – NO CONFIGURATION

- Although 50° and 57° orbits are different (50° orbit is with Skylab while 57° is without Skylab), this analysis represents Power Module and support elements in terms of composite system capability for the combined orbits. Since the Power Module configuration size and timing were similar, this provided a good basis for the analysis.

- The analysis points to an early (1986) use of 50 kW in Scenario I (without Skylab) which allows more power (25 kW each) for Material Processing and STO. More power in this time frame for MPS and STO is consistent with work reported earlier in Part I of the 25 kW Power Module Evolution Study with no apparent need to time share. Scenario II with Skylab reflects an early (1986) opportunity for man to conduct experiments in space on a long term basis. With only 25 kW available, and man requiring 15 to 17 kW, only 8 to 10 kW is left for payloads. The result is time sharing in Scenario II.

GROWTH SYSTEM CAPABILITY ANALYSIS
50° AND 57° ORBITS

1983 TO 1985 SCENARIOS

	POWER MODULE						SUPPORT ELEMENTS											
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	50	22	30$\bar{S}$	365	22	15	2	X	-	X	-	-	-	-	-	-	-	-
NOMINAL B-1 SCENARIO I	25	11	30$\bar{S}$	365	12	8	1	X	-	X	-	-	-	-	-	-	-	-
NOMINAL/SKL SCENARIO II B-1/2	25	11	30$\bar{S}$	365	12	8	1	X	-	X	X	-	-	-	-	-	-	-
NOMINAL B-1 SCENARIO III	25	11	±1.0°	365	6	14	1	X	-	X	-	-	-	-	-	-	-	-

GROWTH SYSTEM CAPABILITY ANALYSIS
50° AND 57° ORBITS

1986 SCENARIO

	POWER MODULE						SUPPORT ELEMENTS											
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	100	44	30S	365	36	20	1	–	X	X	X	X	–	–	–	–	–	–
NOMINAL B-2 SCENARIO I	50	22	30S	365	12	7	1	–	X	X	X	–	–	–	–	–	–	–
NOMINAL/SKL B-3 SCENARIO II	25	11	30S	365	12	7	1	–	X	X	X	X	–	–	–	–	–	–
MINIMUM B-1 SCENARIO III	25	11	±1°	365	6	4	1	–	–	X	X	–	–	–	–	–	–	–

GROWTH SYSTEM CAPABILITY ANALYSIS
50° AND 57° ORBITS

1987 TO 1988 SCENARIOS

	POWER MODULE				DATA		SUPPORT ELEMENTS											
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	100	44	30S̄	365	36	20	1	-	X	X	X	X	-	-	-	-	-	-
NOMINAL B-2 SCENARIO I	50	22	30S̄	365	12	7	1	-	X	X	X	-	-	-	-	-	-	-
NOMINAL B-3 SCENARIO II	25	11	30S̄	365	6	3	1	-	X	X	X	X	-	-	-	-	-	-
MINIMUM B-2 SCENARIO III	50	22	±0.5°	365	3	1	1	-	X	X	X	-	-	-	-	-	-	-

GROWTH SYSTEM CAPABILITY ANALYSIS 50° AND 57° ORBIT

1989 TO 1990 SCENARIOS

	POWER MODULE						SUPPORT ELEMENTS											
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	100	44	$30\bar{S}$	365	41	25	1	-	X	X	X	X	-	-	-	-	-	-
NOMINAL B-3 SCENARIO I	50	22	$30\bar{S}$	365	20	12	1	-	X	X	X	X	-	-	-	-	-	-
NOMINAL/SKL B-4 SCENARIO II	50	22	$30\bar{S}$	365	24	15	1	-	X	X	X	X	-	-	-	-	-	-
MINIMUM B-2 SCENARIO III	50	22	±0.5°	365	16	9	1	-	X	X	X	-	-	-	-	-	-	-

- The Power Module is not available until 1988. In the meantime some composite system capability is met by the Orbiter/PEP Sortie.

- The analysis suggests that although the Power Module is only 25 kW, the type and power demands of payloads developed by this time (Scenario I and II – 1988) will result in considerable time sharing, but will allow some study of the sun-earth system from a Polar Orbit vantage point around the time of the solar cycle. While Scenario I, II, or III are equal in deliverable power, only Scenario III enters 1990 with less capability.

GROWTH SYSTEM CAPABILITY ANALYSIS
POLAR ORBIT

1988 TO 1989 SCENARIOS

	POWER MODULE						SUPPORT ELEMENTS											
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	100	44	$30\bar{S}$	365	12	10	1	X	-	X	-	-	-	-	-	-	-	-
NOMINAL C-1 SCENARIO I	25	11	$30\bar{S}$	365	12	7	1	X	-	X	-	-	-	-	-	-	-	-
NOMINAL C-1 SCENARIO II	25	11	$30\bar{S}$	365	12	7	1	X	-	X	-	-	-	-	-	-	-	-
MINIMUM SCENARIO III	N/C																	

N/C – NO CONFIGURATION

GROWTH SYSTEM CAPABILITY ANALYSIS
POLAR ORBIT

1990 SCENARIO

	POWER MODULE				DATA		SUPPORT ELEMENTS											
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	100	44	30$\overline{S}$	365	25	25	1	-	X	X	X	X	-	-	-	-	-	-
NOMINAL C-2 SCENARIO I	25	11	30$\overline{S}$	365	12	12	1	-	X	X	X	-	-	-	-	-	-	-
NOMINAL C-2 SCENARIO II	25	11	30$\overline{S}$	365	12	12	1	-	X	X	X	-	-	-	-	-	-	-
NOMINAL C-1 SCENARIO III	25	11	±0.5°	365	6	6	1	-	X	X	X	-	-	-	-	-	-	-

- Scenarios I and II show the 60 kW Power Module in 1987. The 25 to 40 kW power required for Public Service in 1987 corresponds to expected power demands from earlier work in Part I. With a demand of 40 to over 60 percent of 60 kW for Public Service, time-sharing of power will be required among all payloads or use some priority approach.

- Scenario III does not enter the picture until 1988 and with less data and stability features, which could be least desirable under some circumstances.

- Platforms are required in all scenarios.

GROWTH SYSTEM CAPABILITY ANALYSIS
GEO ORBIT

1987 SCENARIO

	POWER MODULE							SUPPORT ELEMENTS										
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	100	44	30S	365	16	5	4	X	-	X	-	-	-	X	-	-	-	X
NOMINAL D-1 SCENARIO I	60	26	30S	365	12	4	1	-	-	X	-	-	-	X	-	-	-	X
NOMINAL D-1 SCENARIO II	60	26	30S	365	12	4	1	-	-	X	-	-	-	X	-	-	-	X
NOMINAL D-1 SCENARIO III	N/C																	

N/C – NO CONFIGURATION

GROWTH SYSTEM CAPABILITY ANALYSIS
GEO ORBIT

1988 TO 1990 SCENARIOS

	POWER MODULE							SUPPORT ELEMENTS										
					DATA													
	POWER (KW)	HEAT REJECTION (KW)	STABILIZATION	MISSION DURATION	ANALOG (MHZ)	DIGITAL (MBPS)	POWER MODULE	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIFIED)	PLATFORM	REMOTE MANIPULATORS	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT
COMPOSITE PAYLOAD REQUIREMENTS	100	44	30S̄	365	16	15	4	X	-	X	-	-	-	X	X	-	-	X
NOMINAL D-1 SCENARIO I	60	26	30S̄	365	12	4	1	-	-	-	-	-	-	X	-	-	-	X
NOMINAL D-1 SCENARIO II	60	26	30S̄	365	12	4	1	-	-	-	-	-	-	X	-	-	-	X
NOMINAL D-1 SCENARIO III	60	26	±0.5°	365	6	2	1	-	-	-	-	-	-	X	-	-	-	X

- The next four charts represents growth system capability analysis in the 28.5° orbit for 1983 through 1991, and presented in four increments of time, 1983 to 1985, 1986 to 1987, 1988 to 1989, and 1990.

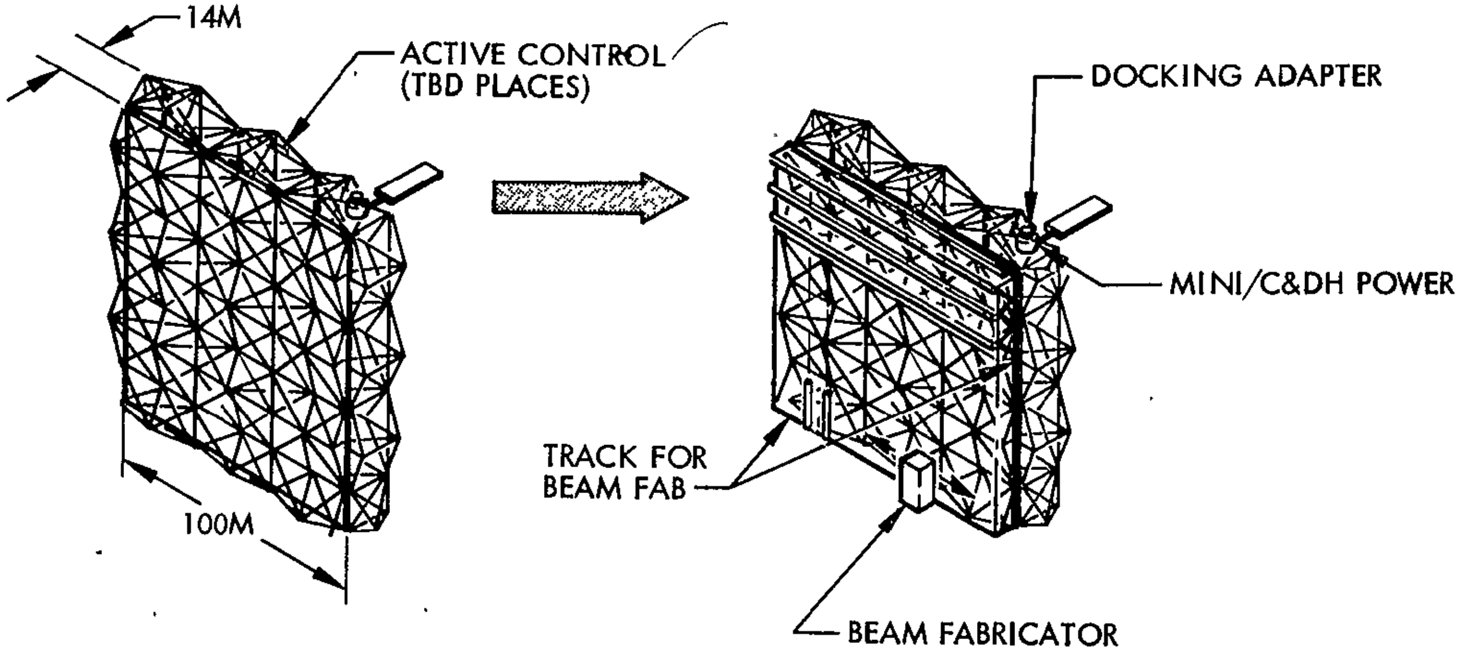
- The data adjacent to "Composite Payload Requirements" represents the Power Module and support element requirements if all demands/needs are provided during that time for the three major disciplines as defined in Part I.

- Under composite system capabilities there are three levels of system capability; ambitious, nominal, and minimum. These levels of capabilities correspond to the terms used in the prior six pages of scenarios and represent the derived capabilities of each system configuration, e.g., power levels, heat rejection, stabilization, etc. during the time period on the particular chart. It also identifies the use of supporting elements at each level of capability.

- These charts provide a direct comparison of the various composite system capabilities against the composite Part I requirements. It assumes early utilizationof the PEP/sortie power and the evolutionary growth of the Power Module. The use of elements and their growth requirements are readily identified from these tables. These element requirements are used for the system and subsystem designs and trade analysis to derive the evolutionary growth options.

CANDIDATE SYSTEM CONFIGURATION
NOMINAL SCENARIO

28.5° ORBIT – 1983-1985
SHUTTLE AUGMENTED SORTIE MISSIONS

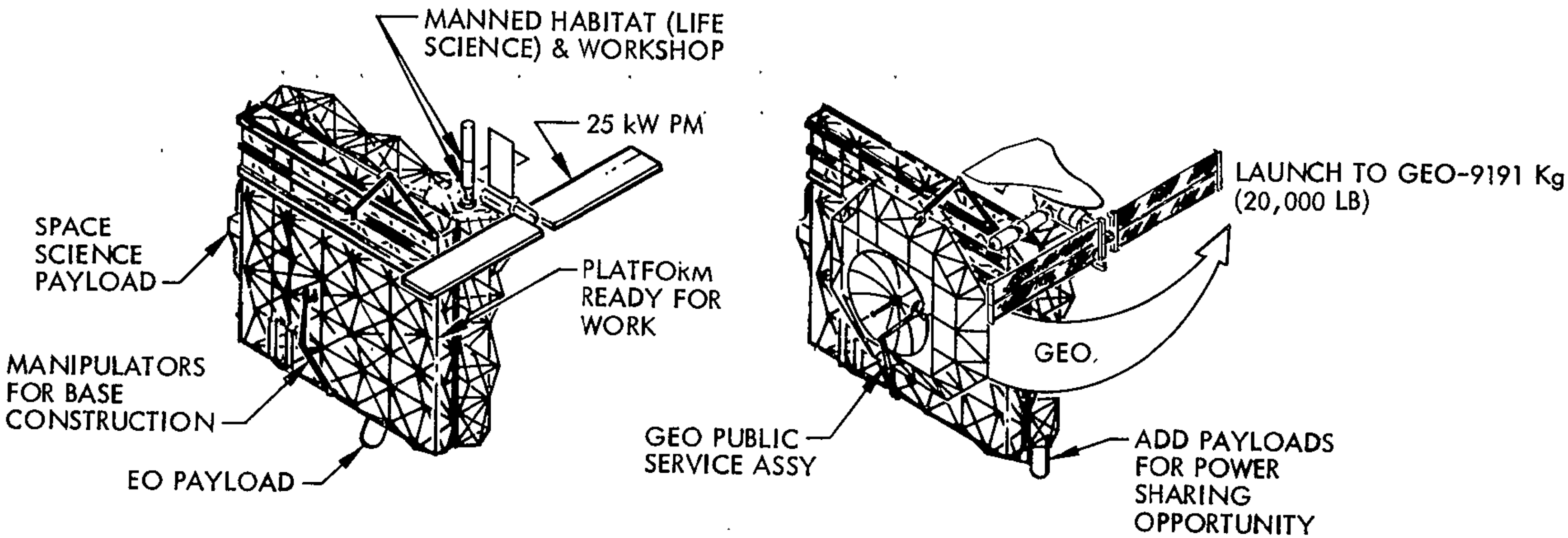


- In 1986, a 25 kW Power Module and workshop are added to the construction base to enhance construction capability and permit man-tended payload operations.

- In 1987, the construction base is utilized to construct a public service platform which is subsequently transferred to GEO.

CANDIDATE SYSTEM CONFIGURATION–NOMINAL SCENARIO EVOLUTION (MIXED PAYLOADS)

28.5° ORBIT – 1986-1987
SORTIE SUPPORTED/FREE FLYER

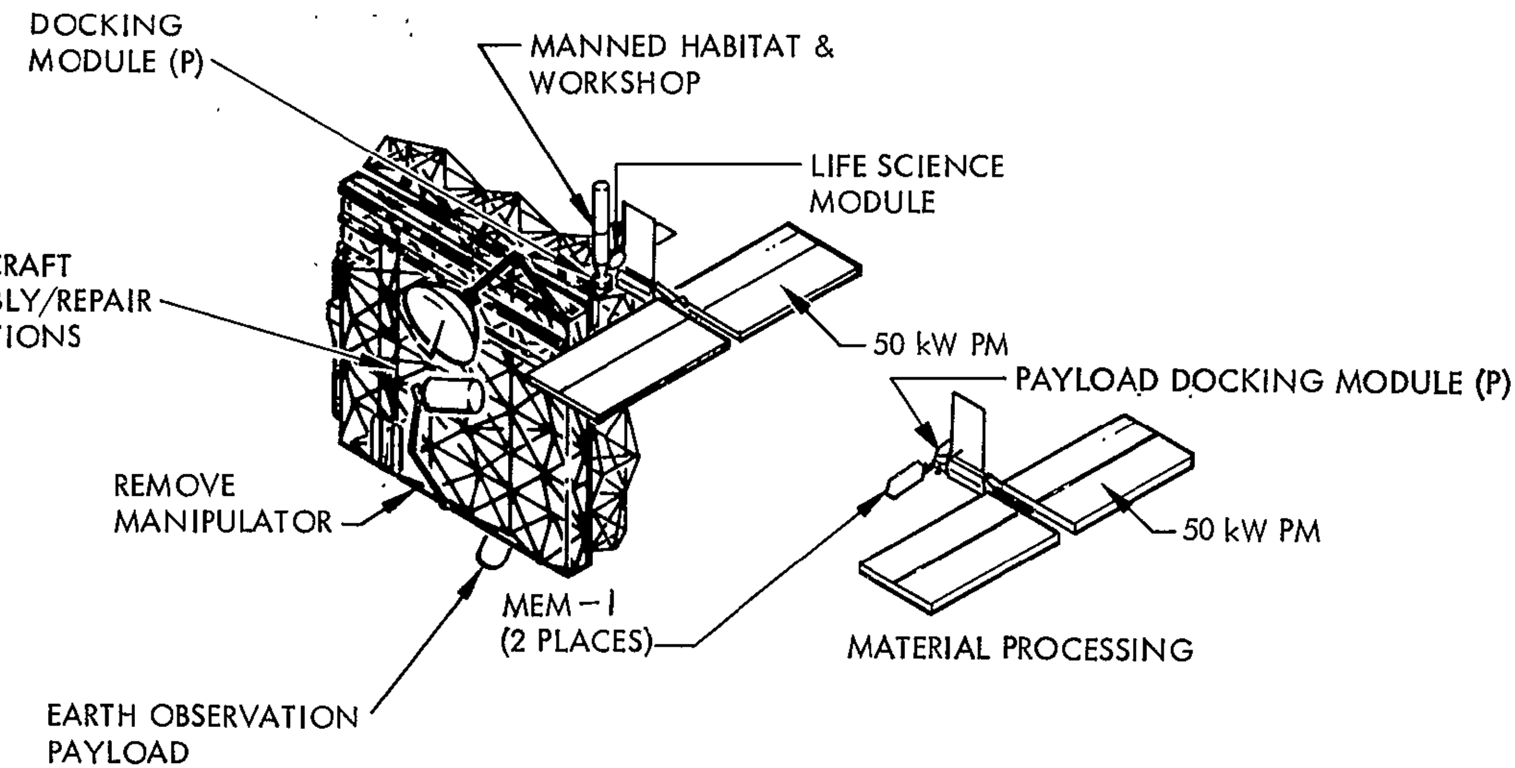


- Habitability is added in 1988 and the 25 kW PM is replaced by a new 50 kW PM. This permits expanded space science and construction capability and the introduction of a LS laboratory. This new 50 kW PM is capable of growth on-orbit to 100 kW in 1990.

- In 1989 a separate 50 kW PM supported facility is placed in this orbit to conduct manned MPS experiment/development operations. The PM for this facility can grow on-orbit to 100 kW when later unmanned production begins.

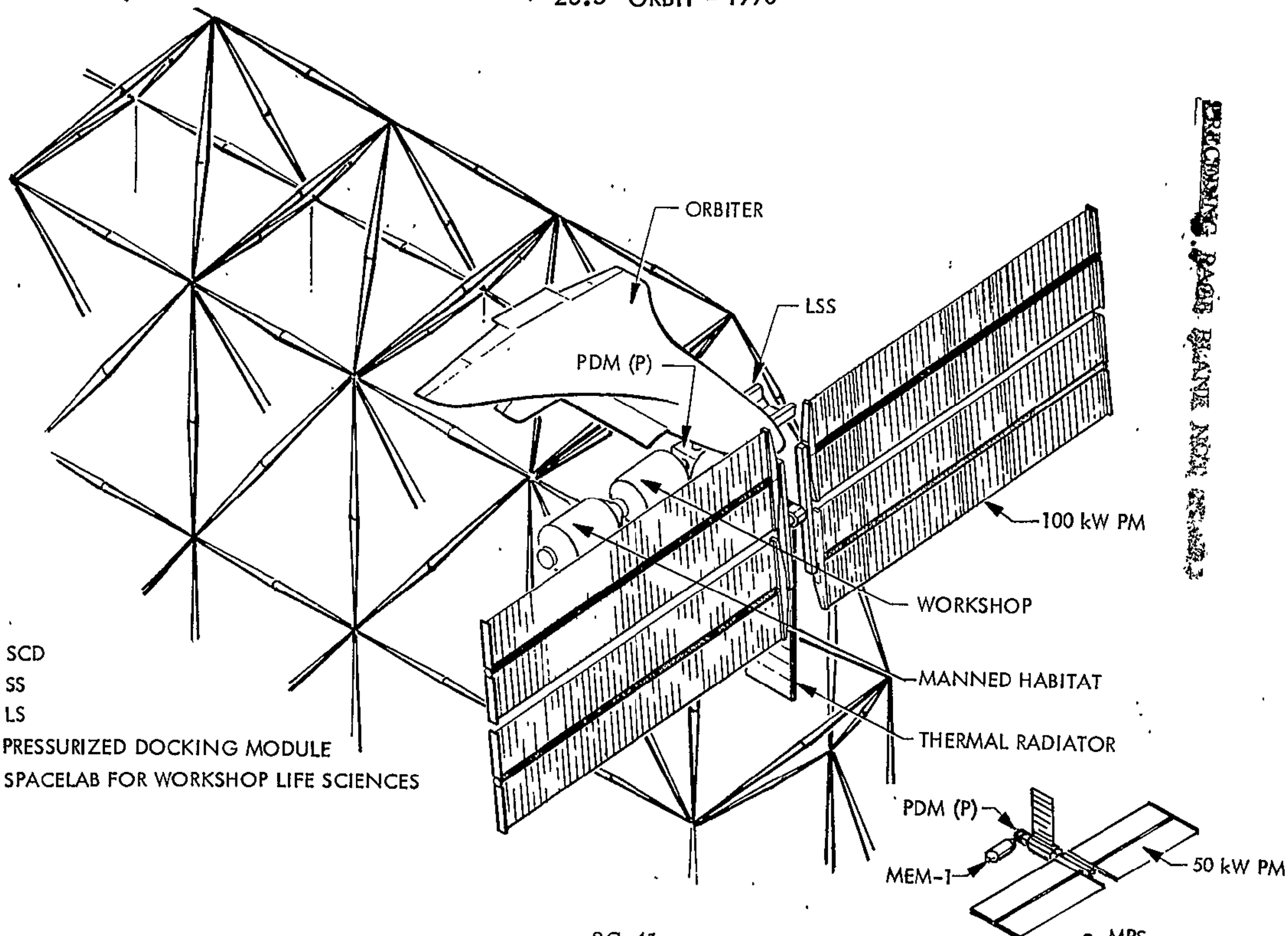
CANDIDATE SYSTEM CONCEPT CONFIGURATION
NOMINAL SCENARIO

28.5° ORBIT - 1988-1990



CANDIDATE SYSTEM CONFIGURATION
NOMINAL SCENARIO

· 28.5° ORBIT – 1990



SCD
SS
LS
PRESSURIZED DOCKING MODULE
SPACELAB FOR WORKSHOP LIFE SCIENCES

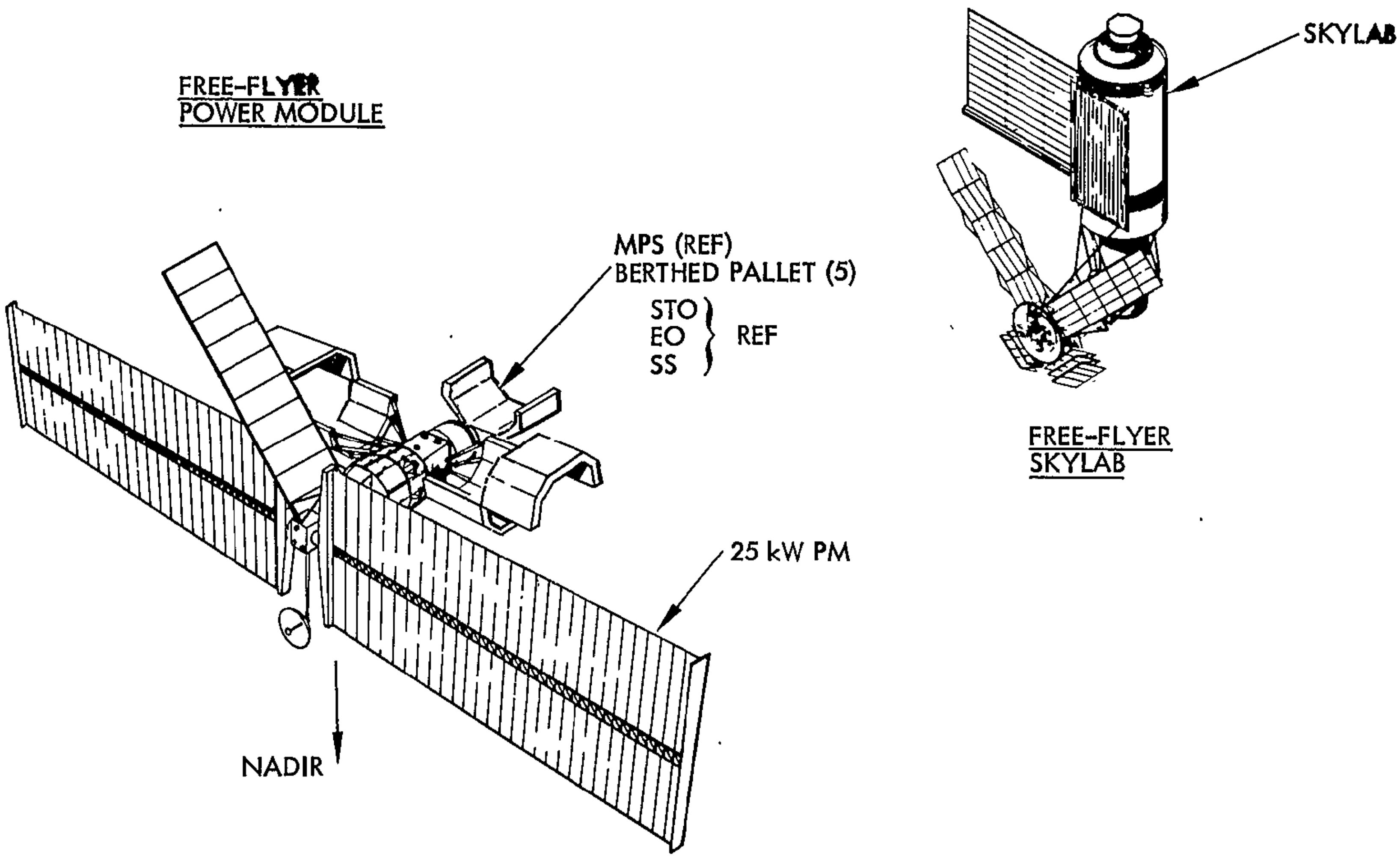
• MPS

NOMINAL MANNED FREE-FLYER

- The next three charts cover three time brackets, 1984 to 1985, 1986 to 1988, and 1989 in the nominal case as a manned free-flyer.
- They reflect: (1) the use of Skylab to enable man to interact with mixed payloads, (2) the configuration, reference orientation, and interfaces of the payloads, and (3) the three-step evolution of the Power Modules from 1984 to 1989.
- In this configuration the scientific and commercial community could have an opportunity to obtain a modes program reasonably economically.

CANDIDATE SYSTEM CONCEPT EVOLUTION (MIXED PAYLOADS)

50° ORBIT NOMINAL SCENARIO (1983)

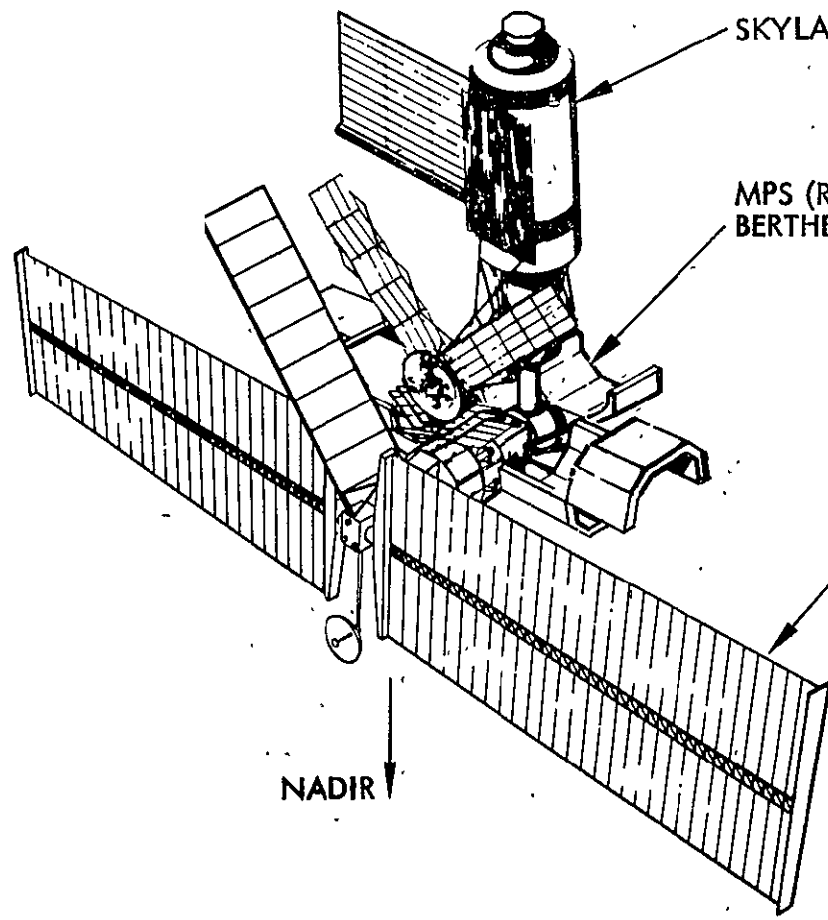


- The early Skylab reuse missions require the Power Module to support both longer-duration sortie missions and free-flyer payloads.

- The Skylab Interface Module is assumed to have been developed to conduct the initial Skylab revisit. This Skylab module would interface with a pressurized Payload Docking Module for shirt-sleeve operations between the Orbiter, Materials Experiment Module (MEM I), and Skylab.

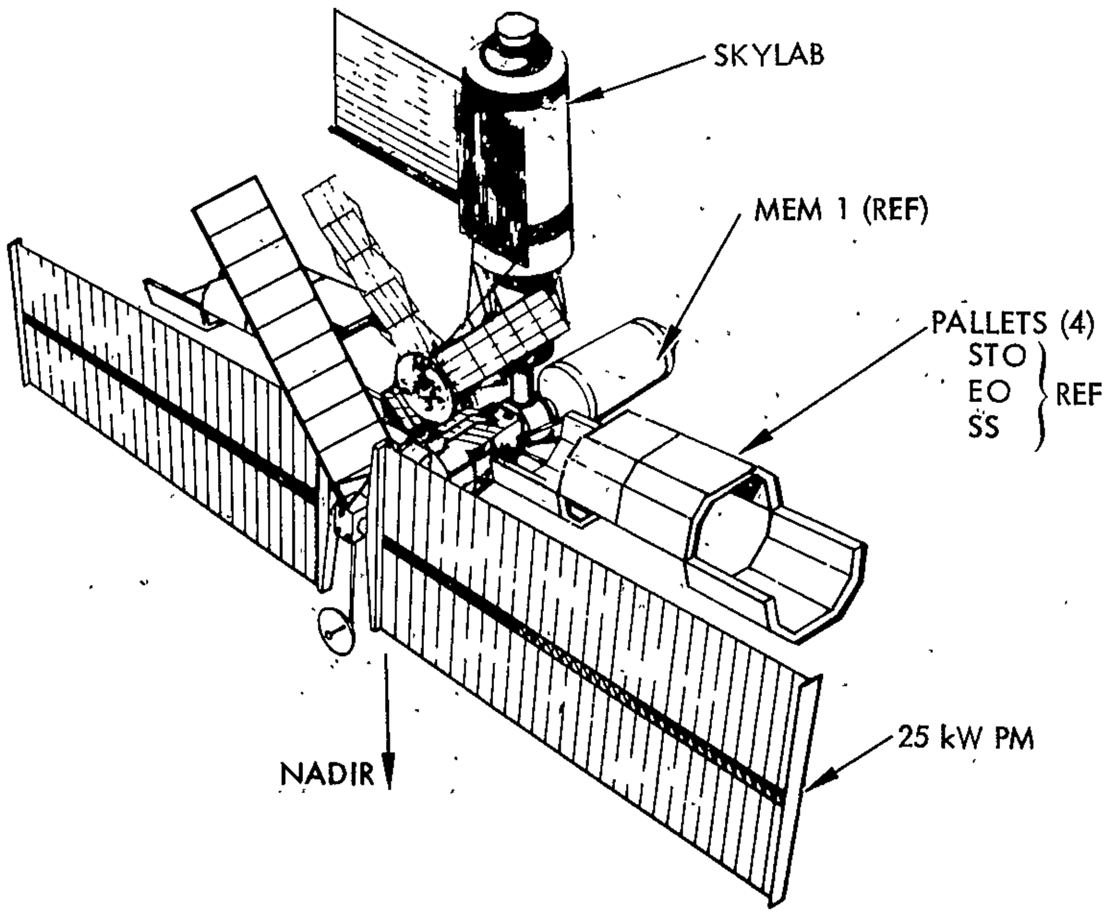
CANDIDATE SYSTEM CONCEPT EVOLUTION (MIXED PAYLOADS)

50° ORBIT NOMINAL SCENARIO
1984-1985



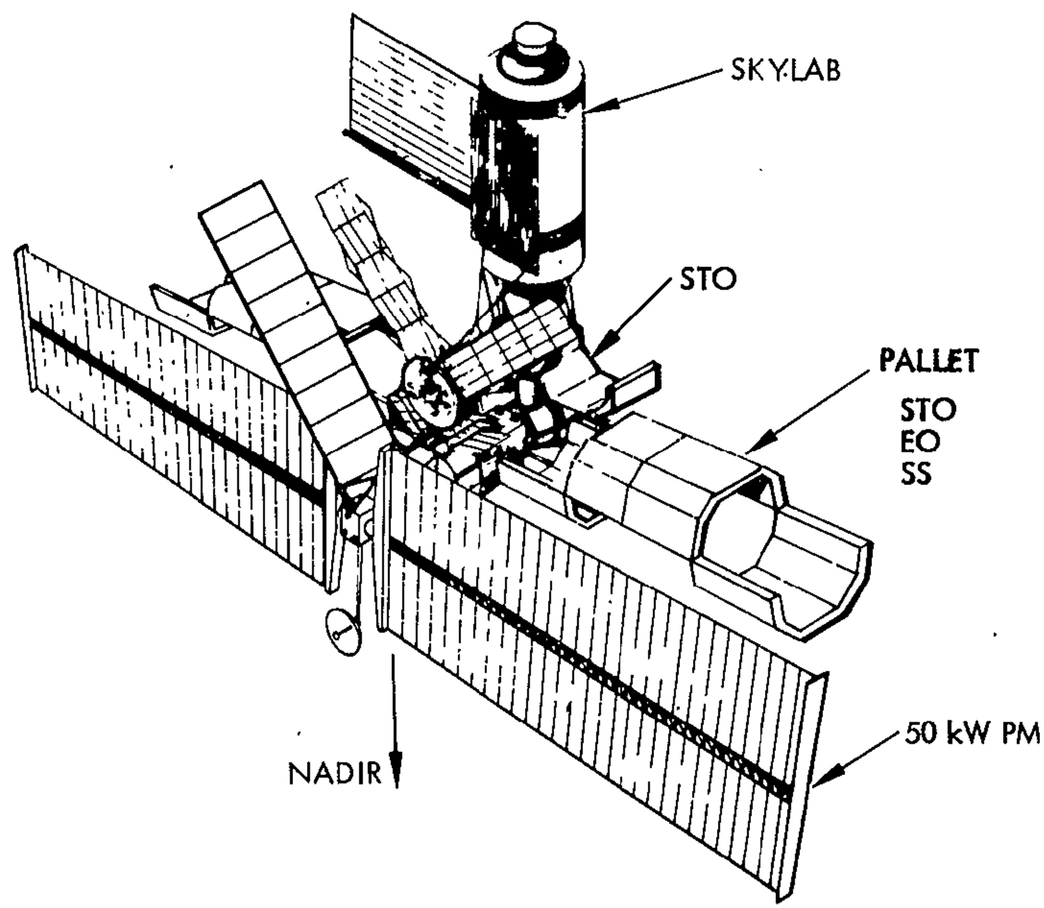
CANDIDATE SYSTEM CONCEPT EVOLUTION (MIXED PAYLOADS)

CANDIDATE SYSTEM CONCEPT EVOLUTION (MIXED PAYLOADS)
50° ORBIT NOMINAL SCENARIO 1986 TO 1988



CANDIDATE SYSTEM CONCEPT EVOLUTION (MIXED PAYLOADS)

50° ORBIT NOMINAL SCENARIO
1989 TO 1990



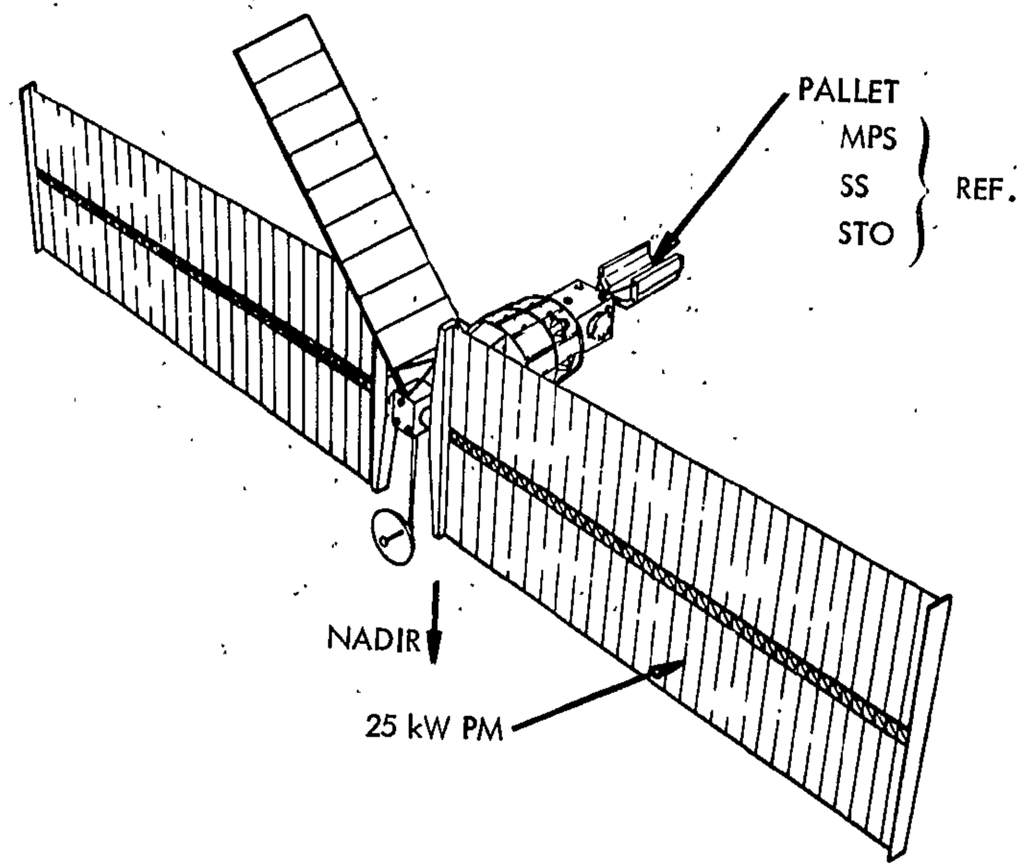
- The next three pages represent Growth System Capability Analysis in the 57° orbit for 1983 to 1990 and is presented in three time brackets, 1983 to 1985, 1986 to 1988, and 1989 to 1990.

- There is generally a good match between System Support Element Capabilities and demands/needs of the Composite Payload Requirements. Here again, the Power Module capabilities vary widely from less than 30% to 100%.

- Generally, Power Module level and technolgy improvements would be needed in 1989 to 1990 to provide at least 50% capabilities in most areas.

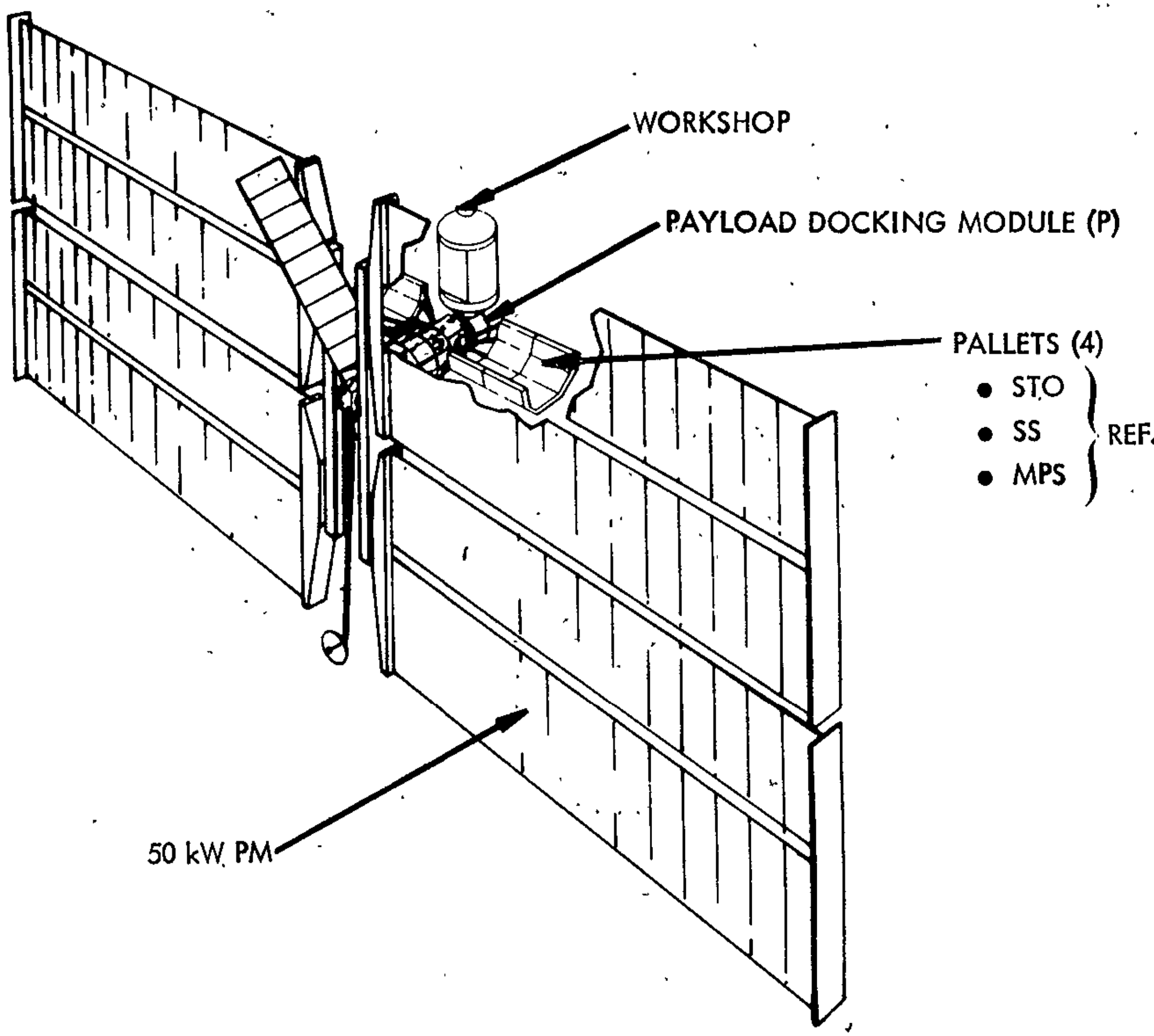
CANDIDATE SYSTEM CONCEPT EVOLUTION (MIXED PAYLOADS)

57° ORBIT NOMINAL SCENARIO 1983–1985



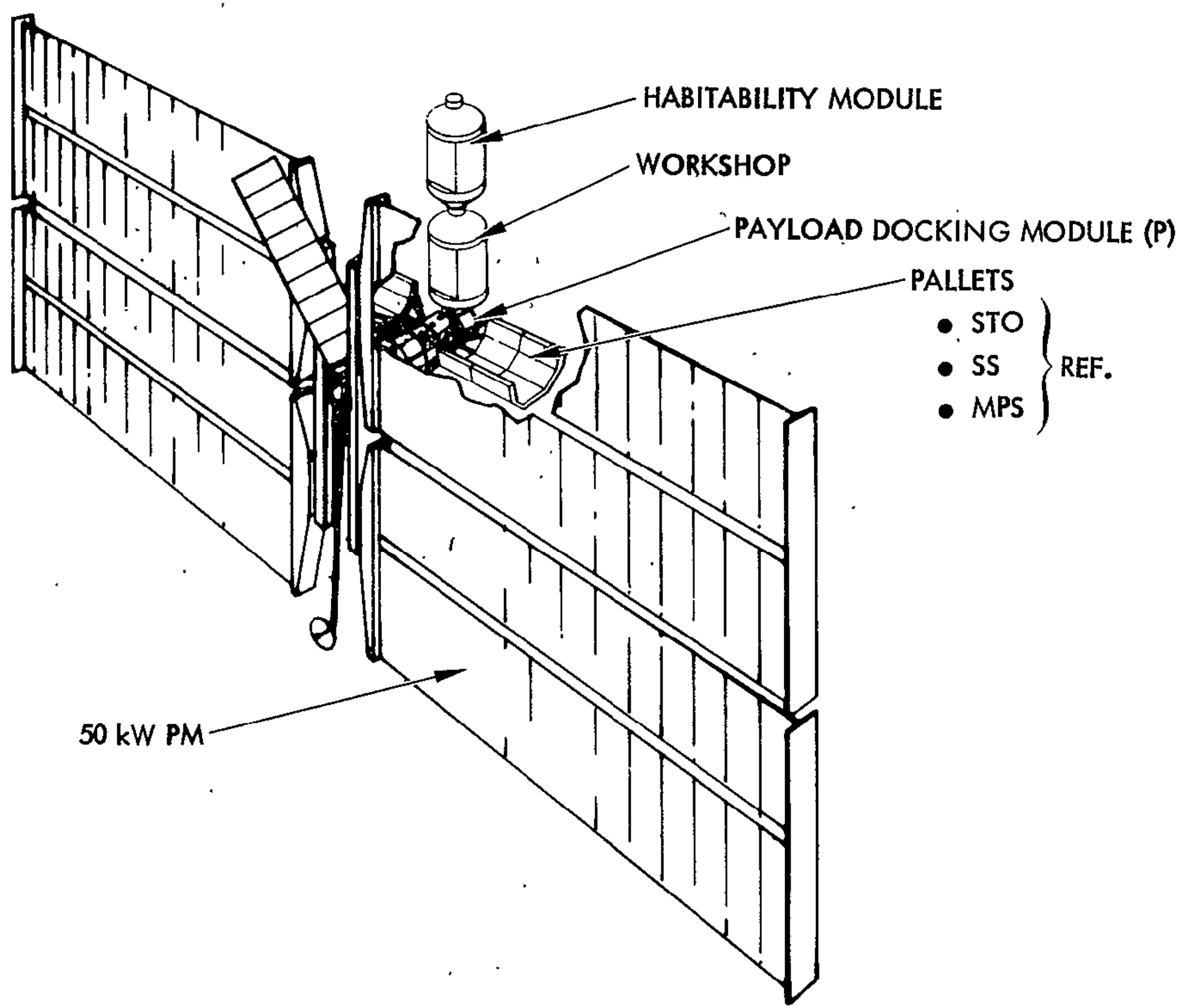
CANDIDATE SYSTEM CONFIGURATION
NOMINAL SCENARIO (MIXED PAYLOADS)

57° ORBIT 1986 - 1988



CANDIDATE SYSTEM CONFIGURATION NOMINAL SCENARIO (MIXED PAYLOADS)

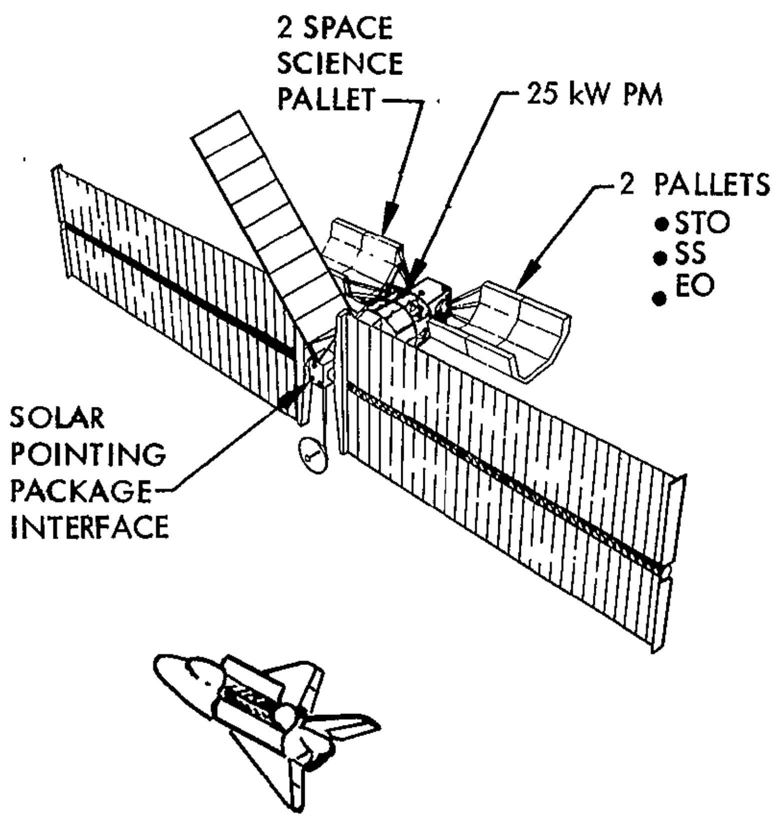
1989 -



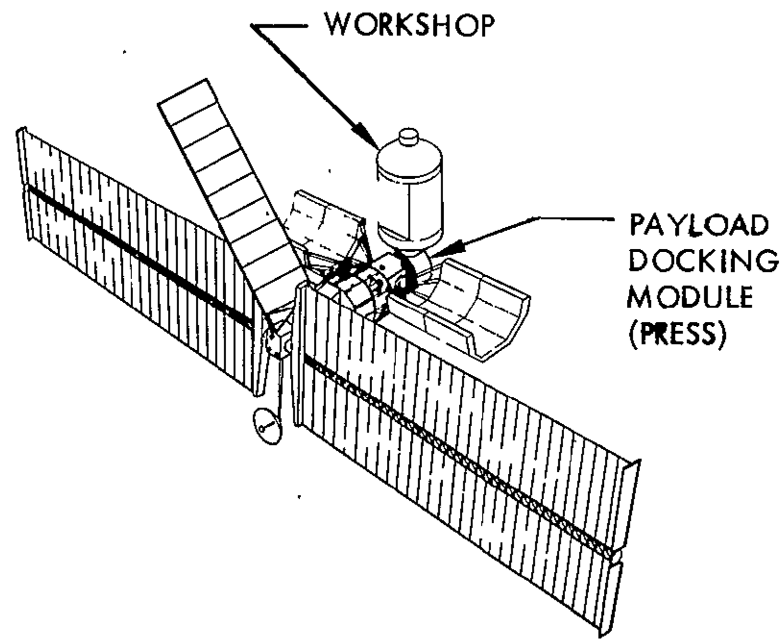
This chart is a scenario for a nominal case, unmanned free-flyer in polar orbit. It is a mixed payload to STO (pallets and solar pointing package), Space Sciences pallets, and Earth Observation and requires use of the Shuttle. A minimum of a 25 kW Power Module will be required from 1988 on.

CANDIDATE SYSTEM CONFIGURATION SCENARIO-POLAR ORBIT

1988



1990+



PM GROWTH
PROGRAMMATICS

PART II PROGRAMMATICS

The six scenarios developed during Part II were expanded in definition to permit broad assessment of the general time phasing and funding requirements for each. The schedule considerations and resulting estimates of funding requirements by year are presented in the following sequence of charts.

Groundrules and/or assumptions which guided the schedule data were:

1. A three-year development period (nonrecurring effort) precedes the launch of the first of each growth configuration (i.e., 25 and 50 kW configurations). The 100 kW configuration is assumed fulfilled by the direct augmentation of a second 50 kW Power Module.
2. A three-year period of procurement, manufacturing, test, and prelaunch operations precedes each launch.
3. Since the long lead item is the solar array, a three-year lead time is also required for components for refurbishing retrieved Power Modules.

Groundrules and/or assumptions which guided the cost data development were:

1. Power Module production expenditures and development expenditures, when applicable, were distributed over the three years preceding a launch using a distribution of 25 percent for the first year, 50 percent the second, and 25 percent the third year.
2. Space Transportation System (STS) user charges were charged in the actual year of launch.
3. Refurbishment costs for a Power Module were estimated at 50 percent of initial production-test-checkout estimates.

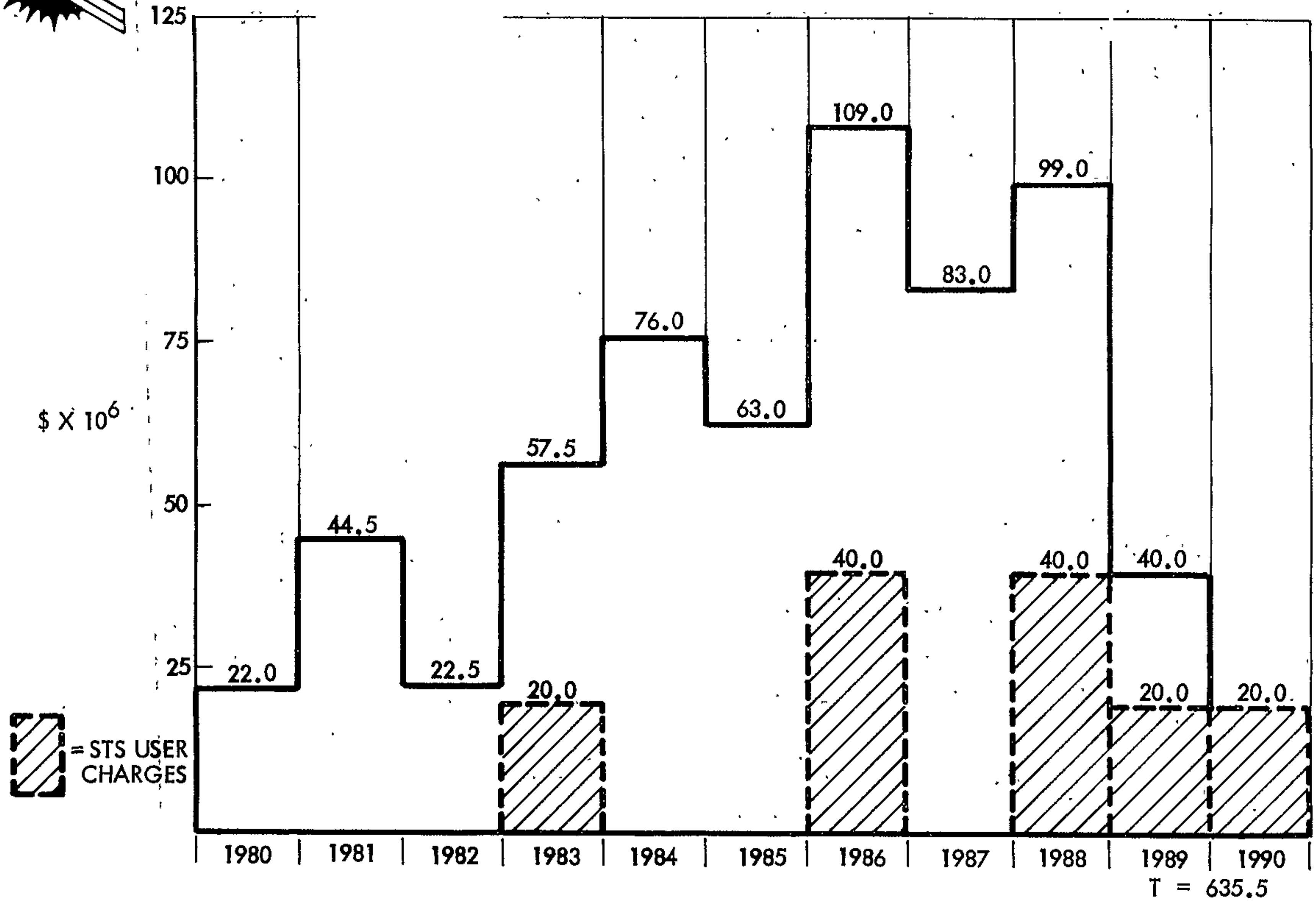
The "Geosync from 28.5^{o} Orbit" mission is excluded from the cost figures because of its specialized mission characteristics.

The estimates do not include ground support for on-orbit operations.

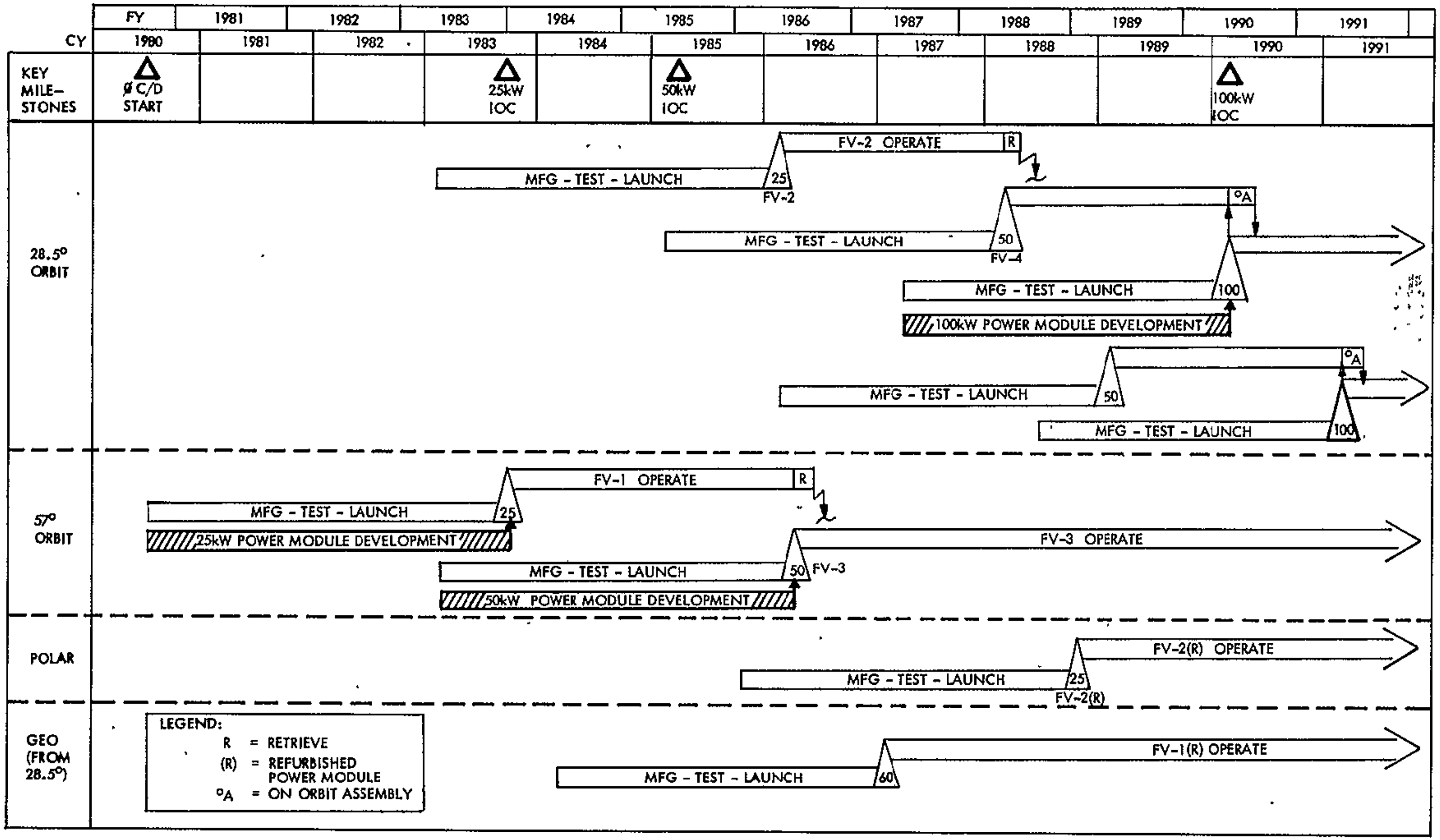
FUNDING REQUIREMENTS BY SCENARIO

	SCENARIO	ESTIMATE OF 1980 TO 1990 FUNDS REQUIRED
I	NOMINAL WITHOUT SKYLAB	$636M
II	NOMINAL WITH SKYLAB	
III	MINIMUM WITHOUT SKYLAB	$536M
IV	MINIMUM WITH SKYLAB	
V	AMBITIOUS WITHOUT SKYLAB	$708M
VI	AMBITIOUS WITH SKYLAB	

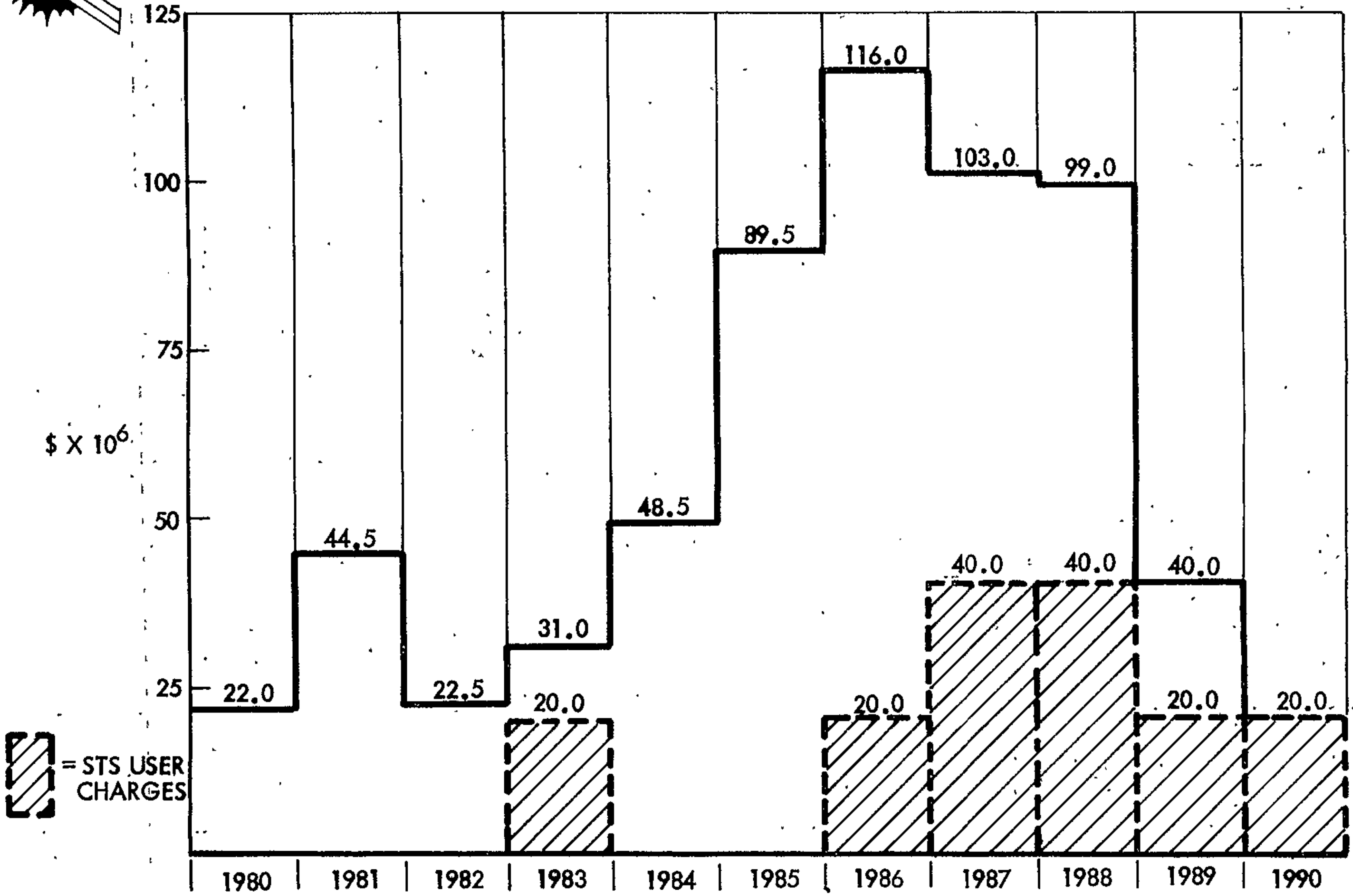
FUNDING PROJECTION FOR SCENARIO I (NOMINAL – NO SKYLAB)



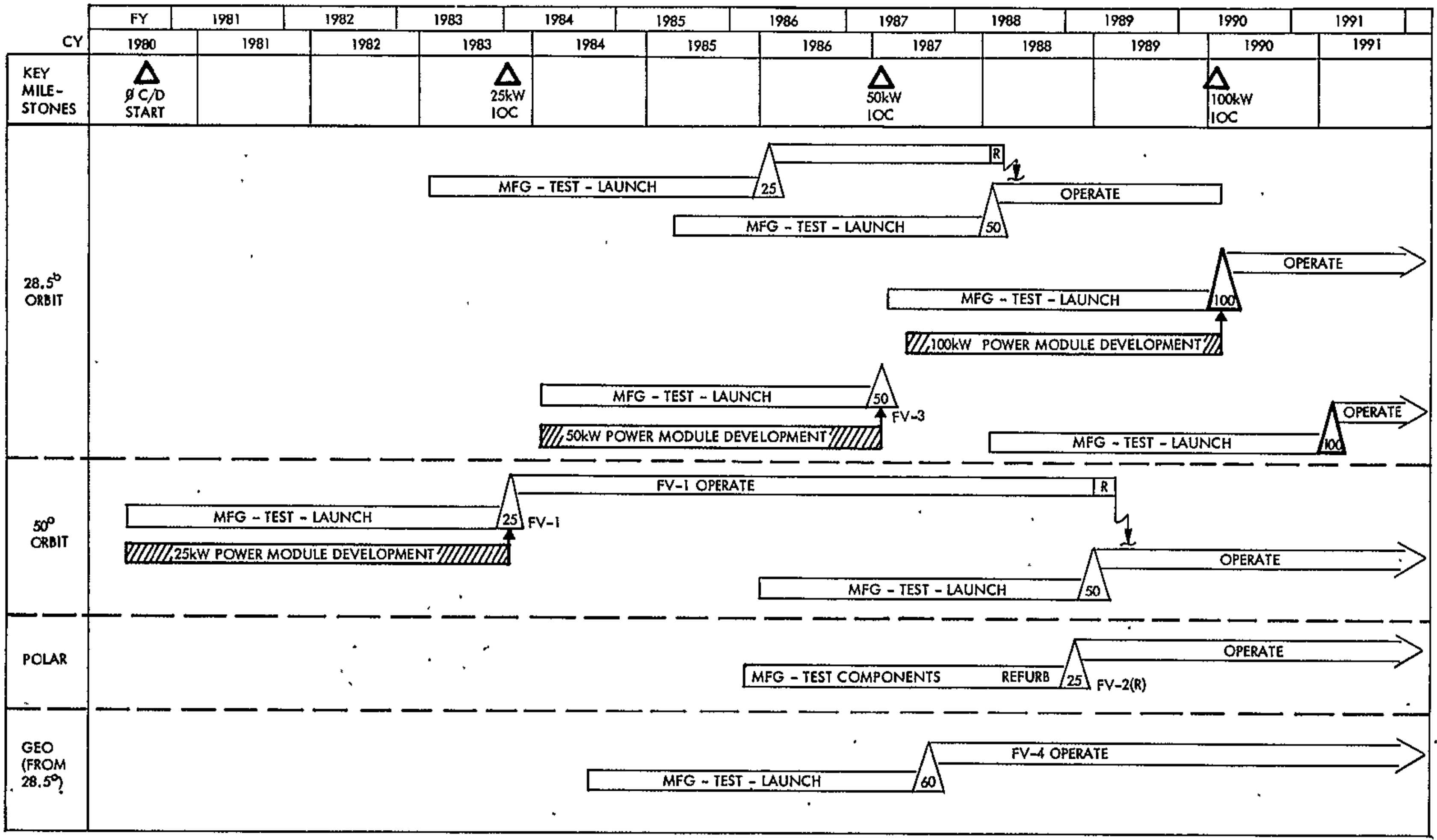
SCENARIO I SUMMARY SCHEDULE (NOMINAL – WITHOUT SKYLAB)



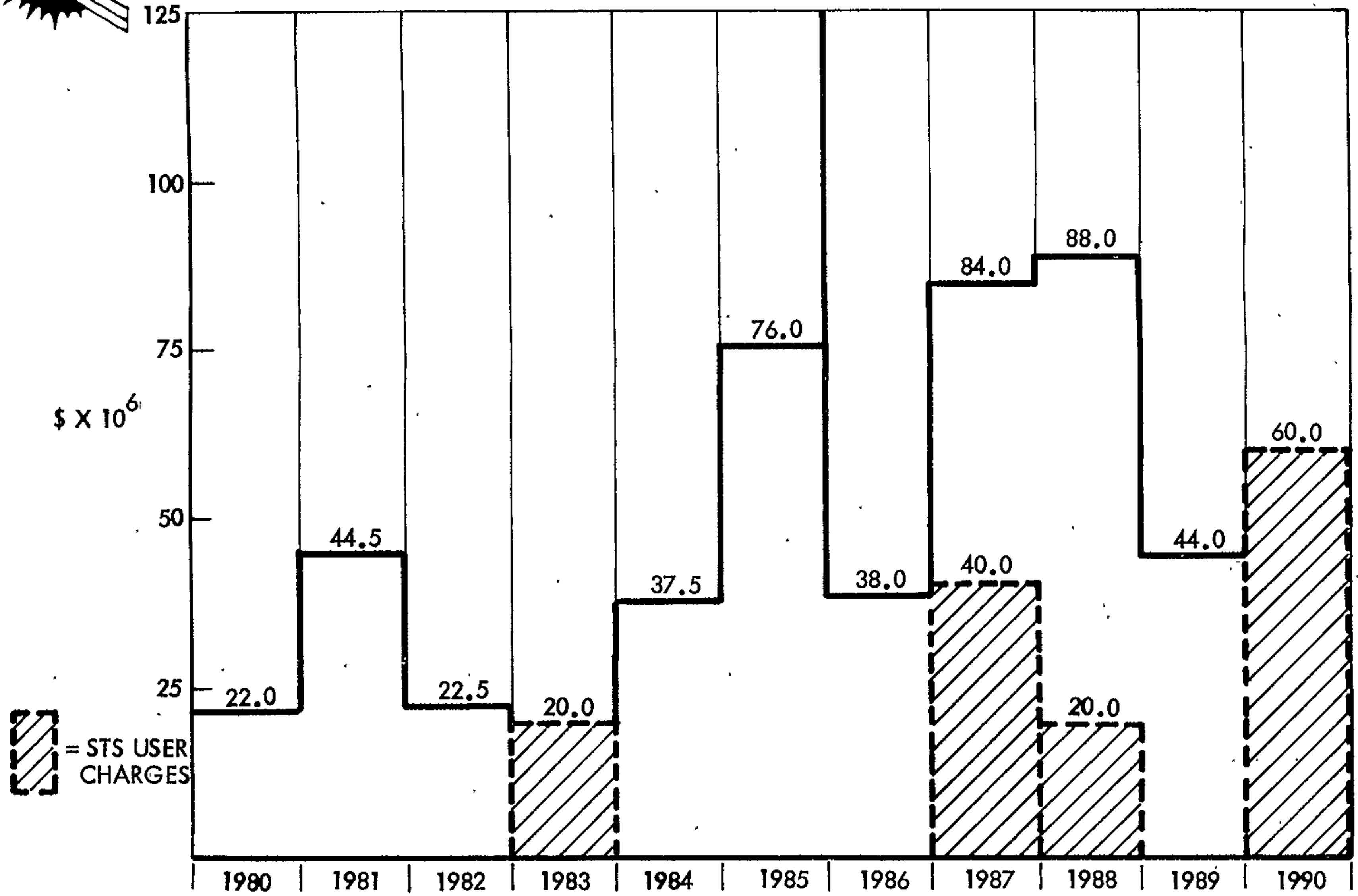
FUNDING PROJECTION FOR SCENARIO II (NOMINAL — WITH SKYLAB)



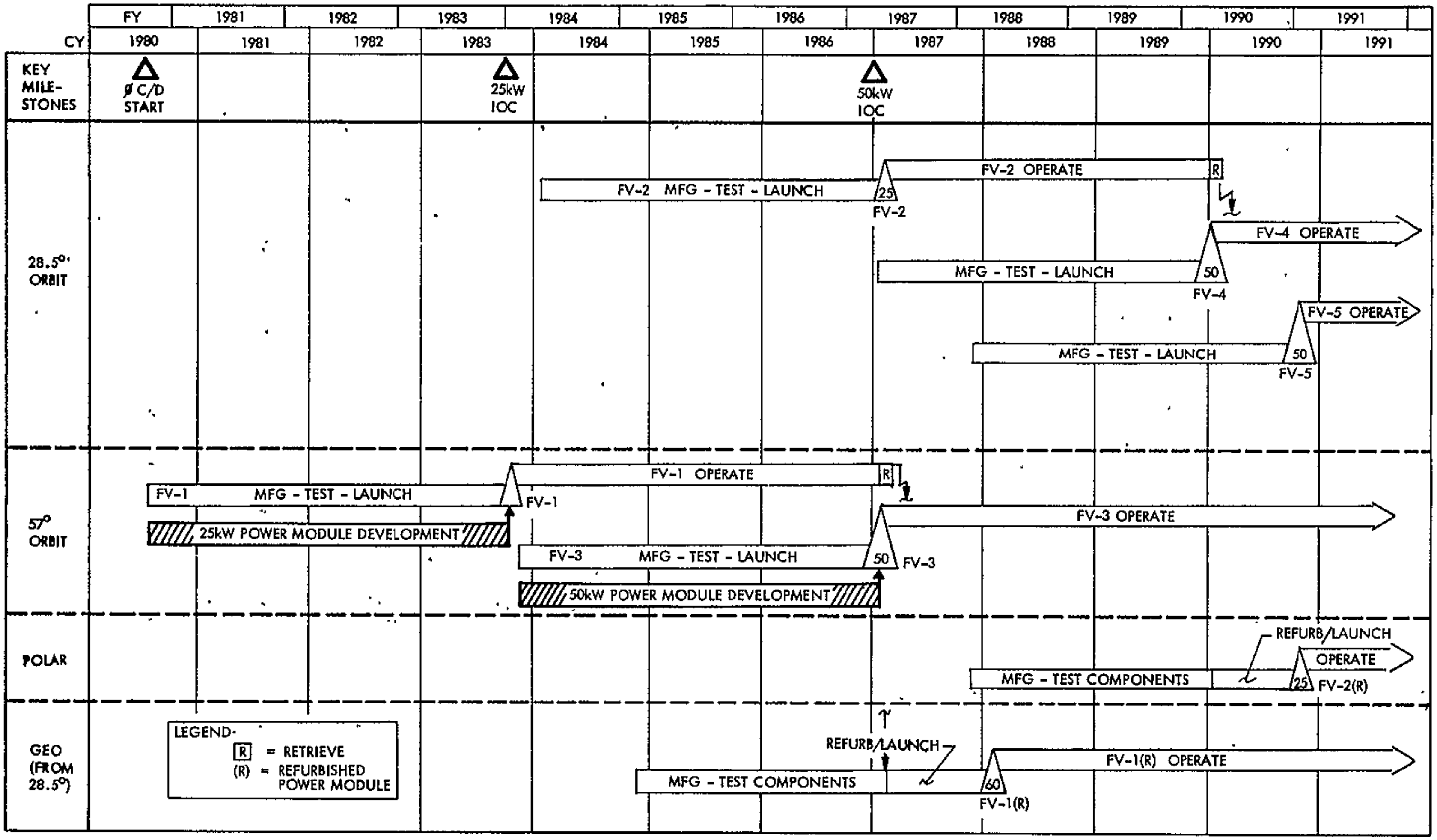
SCENARIO II SUMMARY SCHEDULE (NOMINAL – WITH SKYLAB)



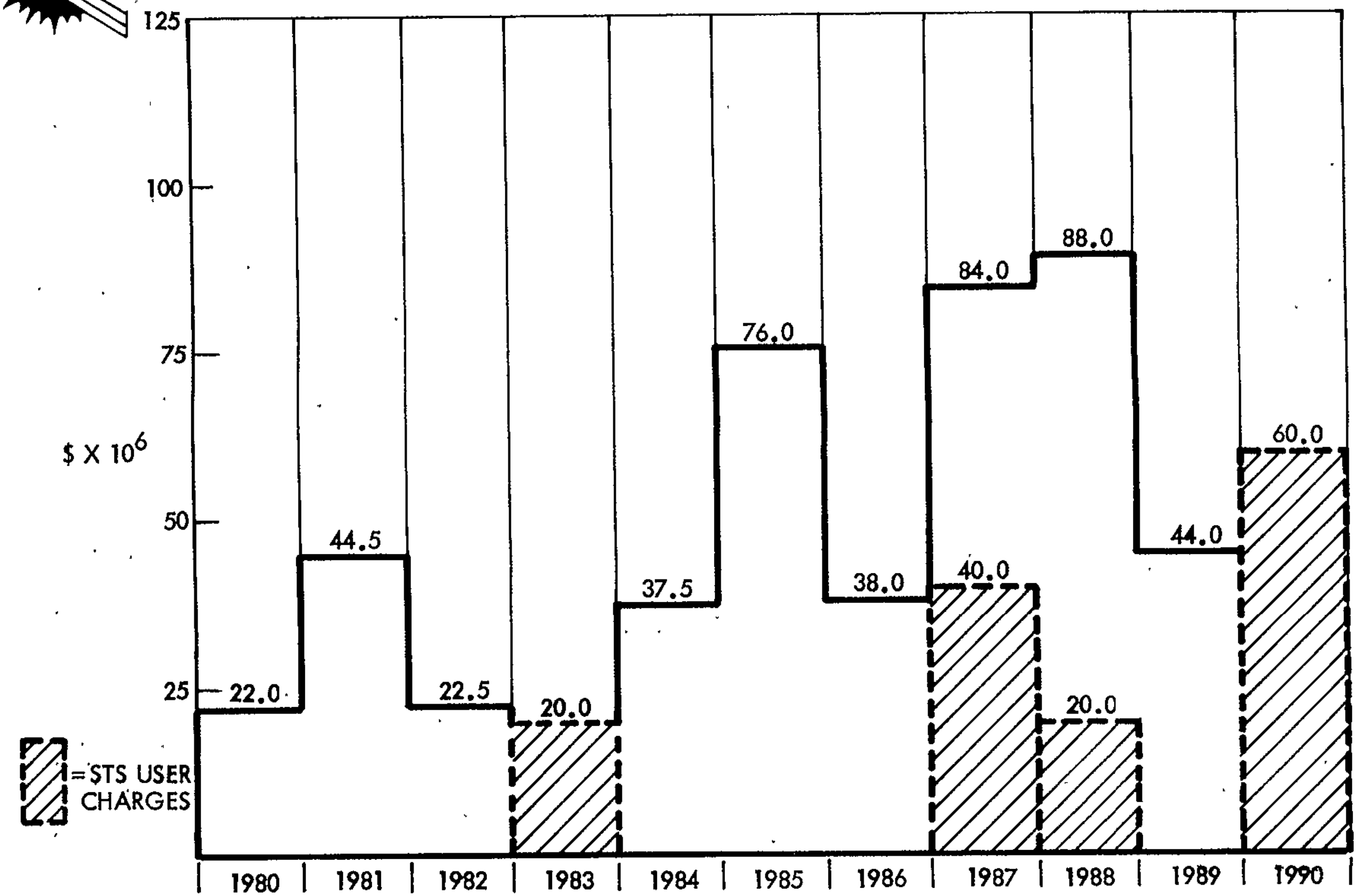
FUNDING PROJECTION FOR SCENARIO III (MINIMUM – WITH SKYLAB)



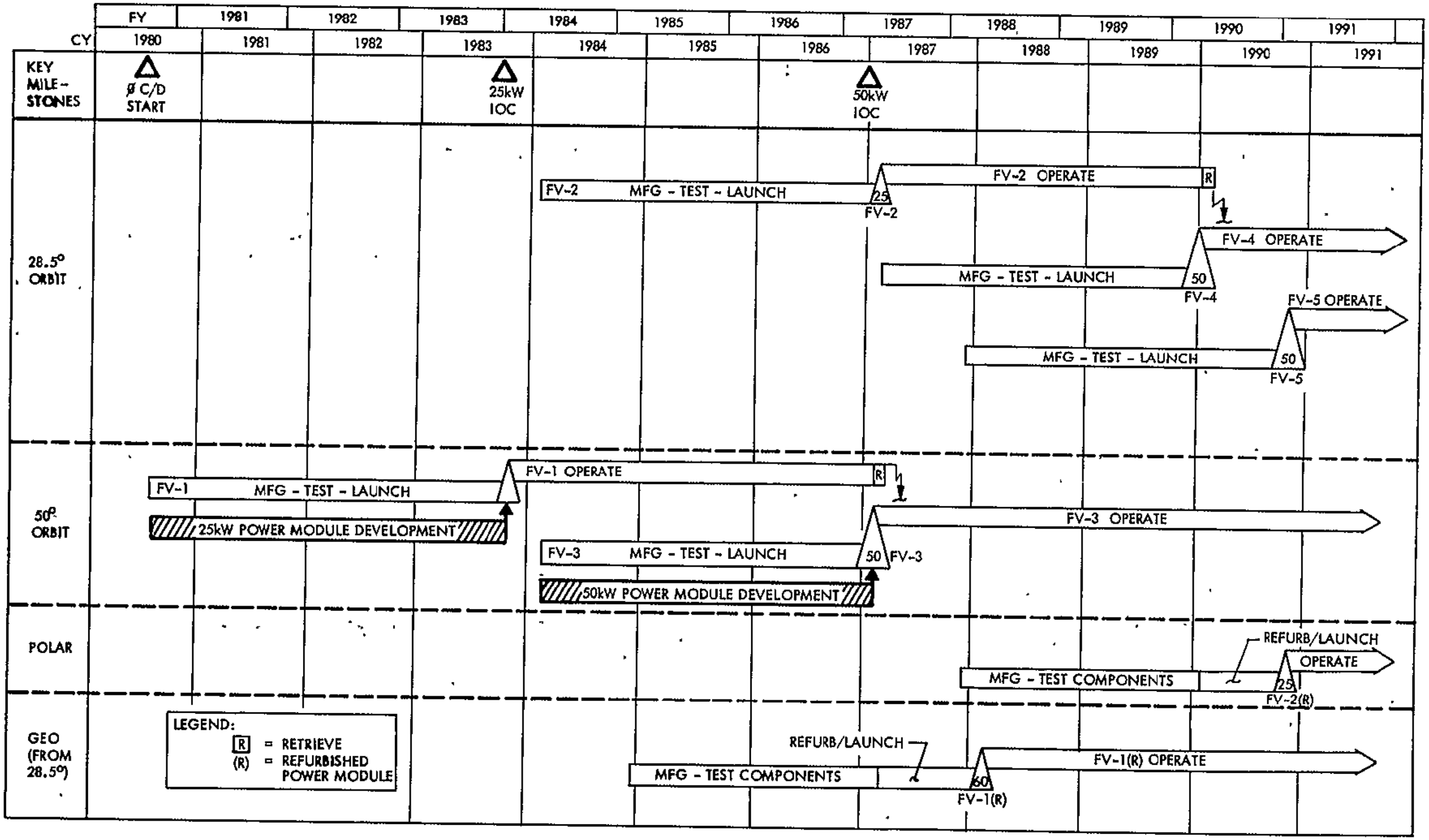
SCENARIO III SUMMARY SCHEDULE
(MINIMUM — WITH SKYLAB)



FUNDING PROJECTION FOR SCENARIO IV
(MINIMUM—NO SKYLAB)



SCENARIO IV SUMMARY SCHEDULE (MINIMUM – WITH SKYLAB)



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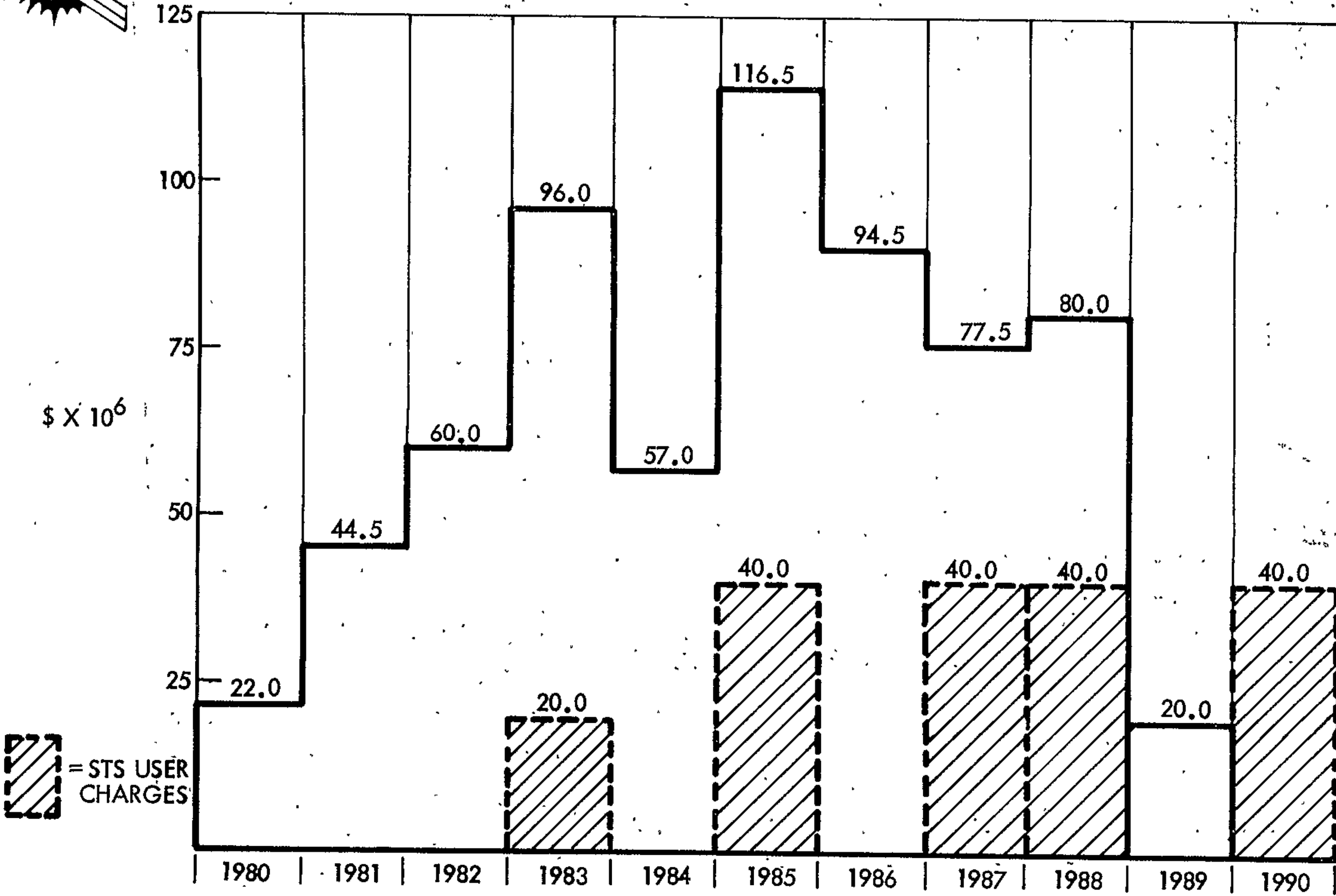
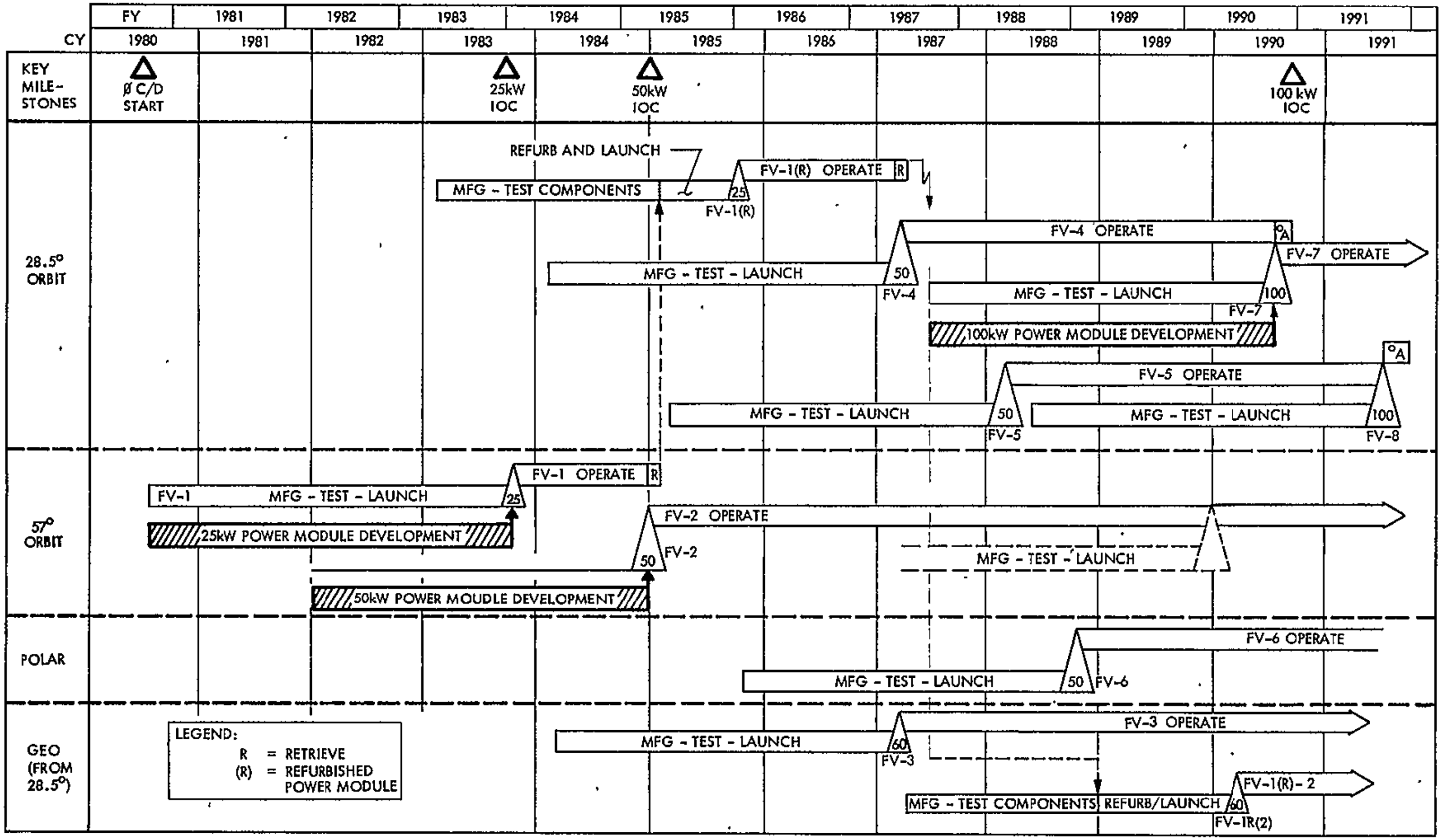
FUNDING PROJECTION FOR SCENARIO V (AMBITIOUS – NO SKYLAB)



PROGRAM SCENARIO V SUMMARY SCHEDULE (AMBITIOUS-NO SKYLAB)



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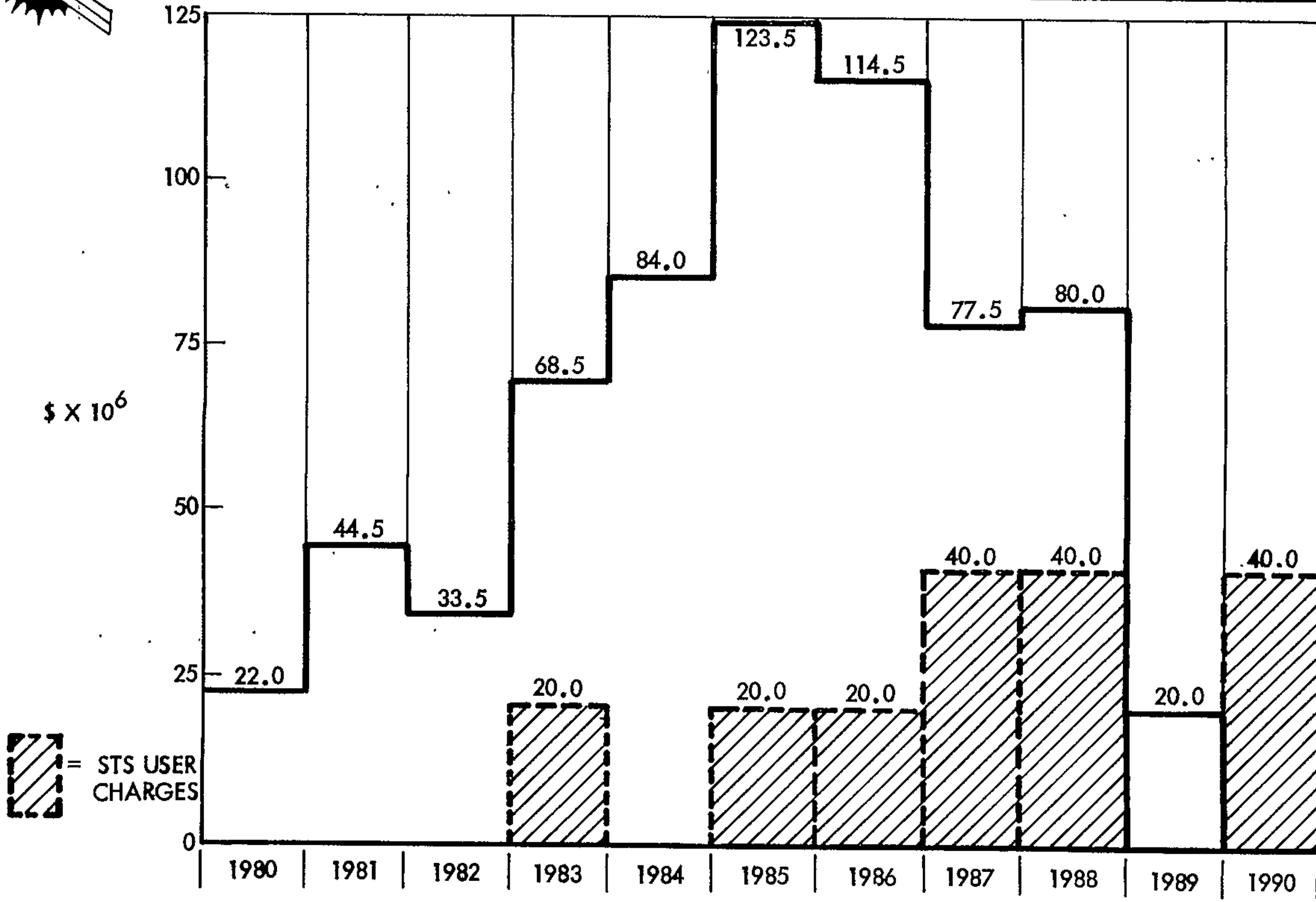
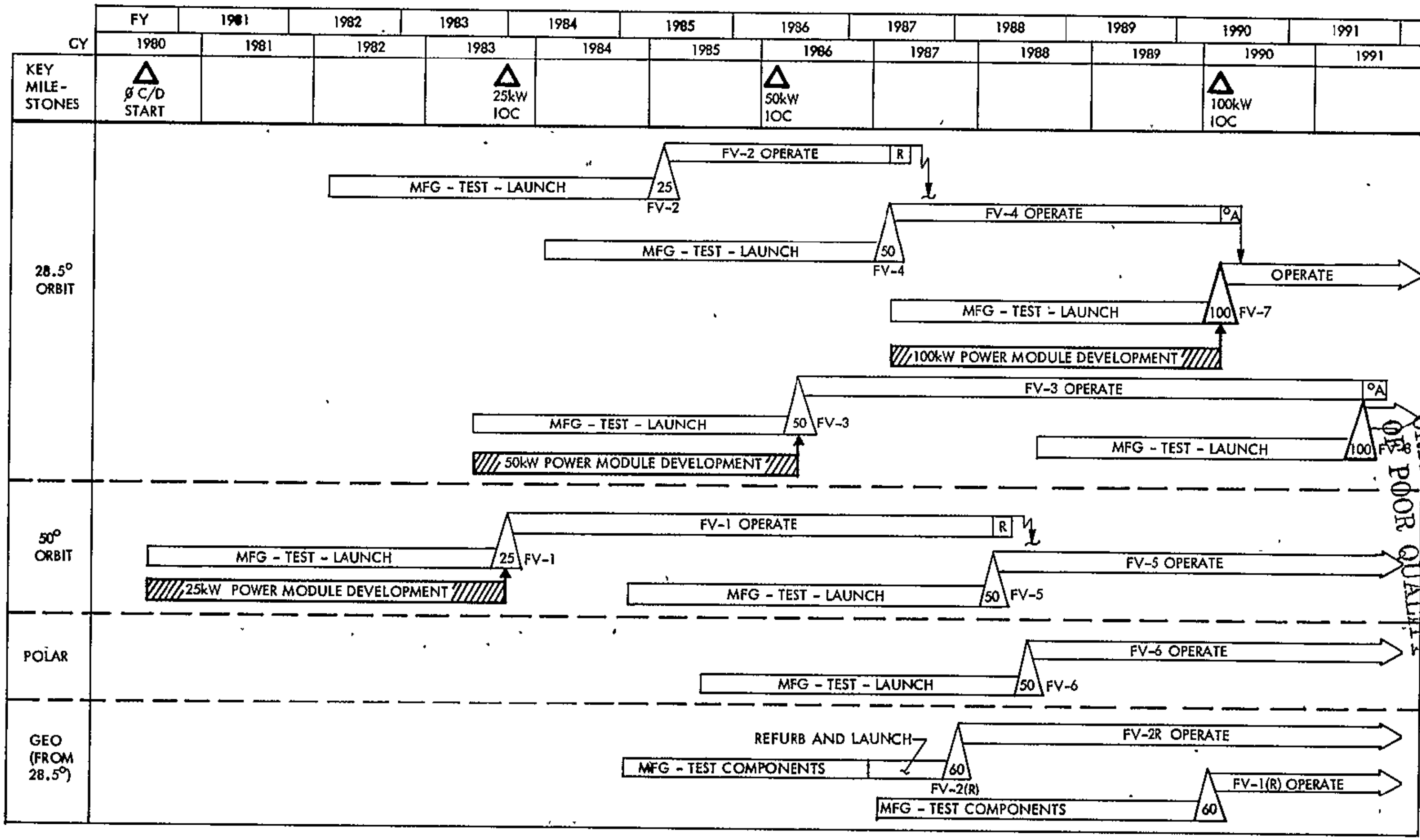
FUNDING PROJECTION FOR SCENARIO VI (AMBITIOUS – WITH SKYLAB)



SCENARIO VI SUMMARY SCHEDULE
(AMBITIOUS – WITH SKYLAB)



RECOMMENDED SYSTEM EVOLUTION & GROWTH OPTIONS

- RECOMMENDATIONS FOR PART III
- CANDIDATE MISSION GROWTH SCENARIOS
- CONSTRUCTION SUPPORT SYSTEM EVOLUTION
- TYPICAL SORTIE
- TYPICAL FREE-FLYER (EVOLUTION?)
- SUBSYSTEM RECOMMENDATIONS
- RECOMMENDED POWER MODULE SYSTEM EVOLUTION

The systems analysis of the evolutionary concepts developed in Part II clearly shows the feasibility of growing the Power Module to meet increasing payload utilization by combining payloads and providing each of the users a highly useful capability. Sharing these resources and stretching out the missions are advisable for most disciplines. It is, therefore, recommeded that the developed nominal scenario, with and without Skylab and the minimum scenario without Skylab be developed for further analysis in Part III.

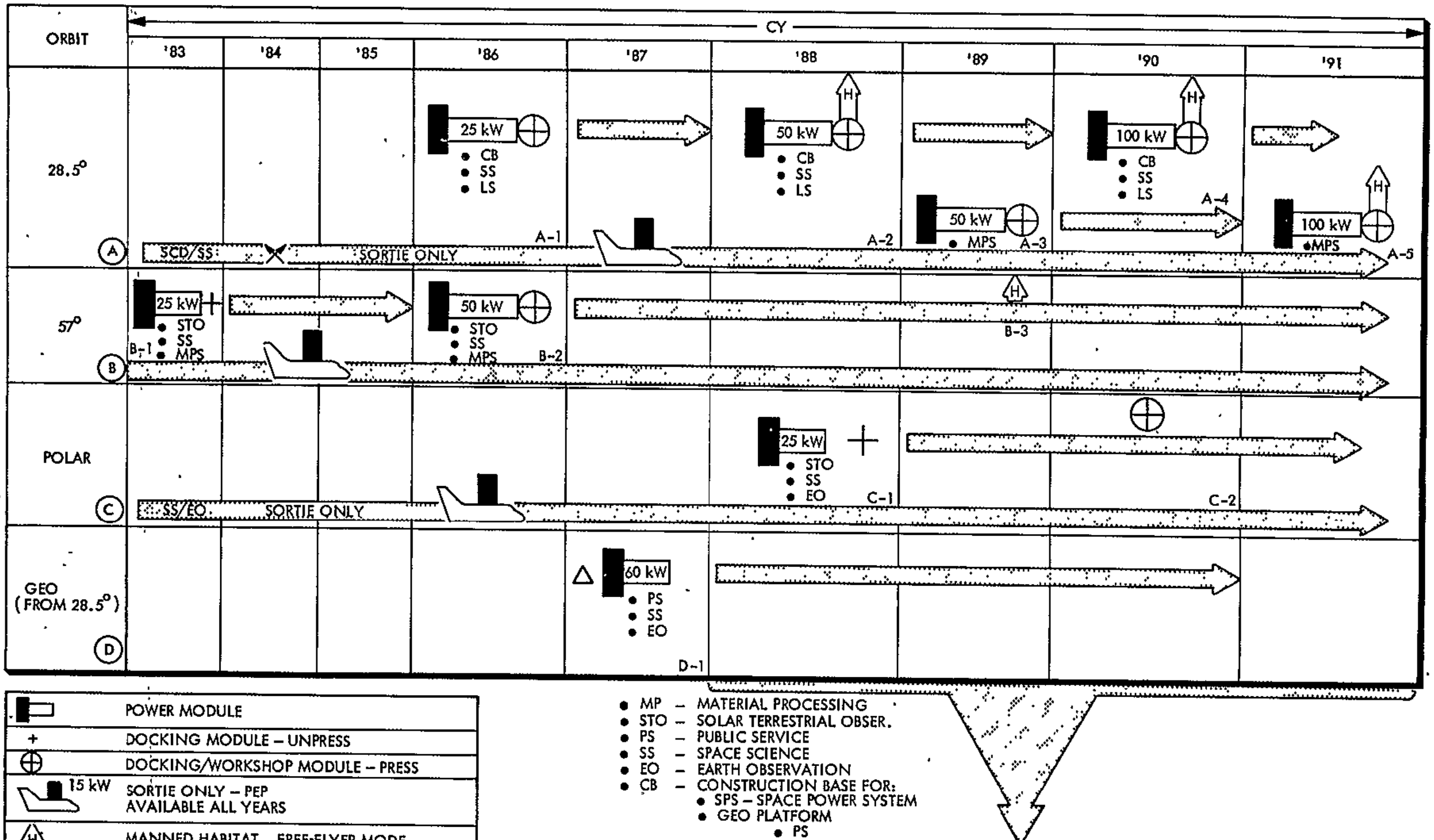
The Power Module growth options need to be examined in more detail to develop subsystem growth options and determine the level of capability that will be included in the Power Module and that capability which would best be provided by additional elements.

The scenarios selected for Part III will then be analyzed at each evolutionary stage so that the relationships between each are described adequately to develop the program plans, costs, and schedules.

RECOMMENDATIONS FOR PART III STUDY

- MISSION GROWTH SCENARIOS
  - NOMINAL NO SKYLAB
  - NOMINAL WITH SKYLAB
  - MINIMUM NO SKYLAB
- PM GROWTH OPTIONS TO 250 kW (1990s)
- DEFINE PM SUBSYSTEM DESIGN APPROACHES FOR EACH EVOLUTIONARY CONFIGURATION AND RELATIONSHIP BETWEEN EACH
- DEVELOP THE RELATED PROGRAM PLANS, COSTS AND SCHEDULES

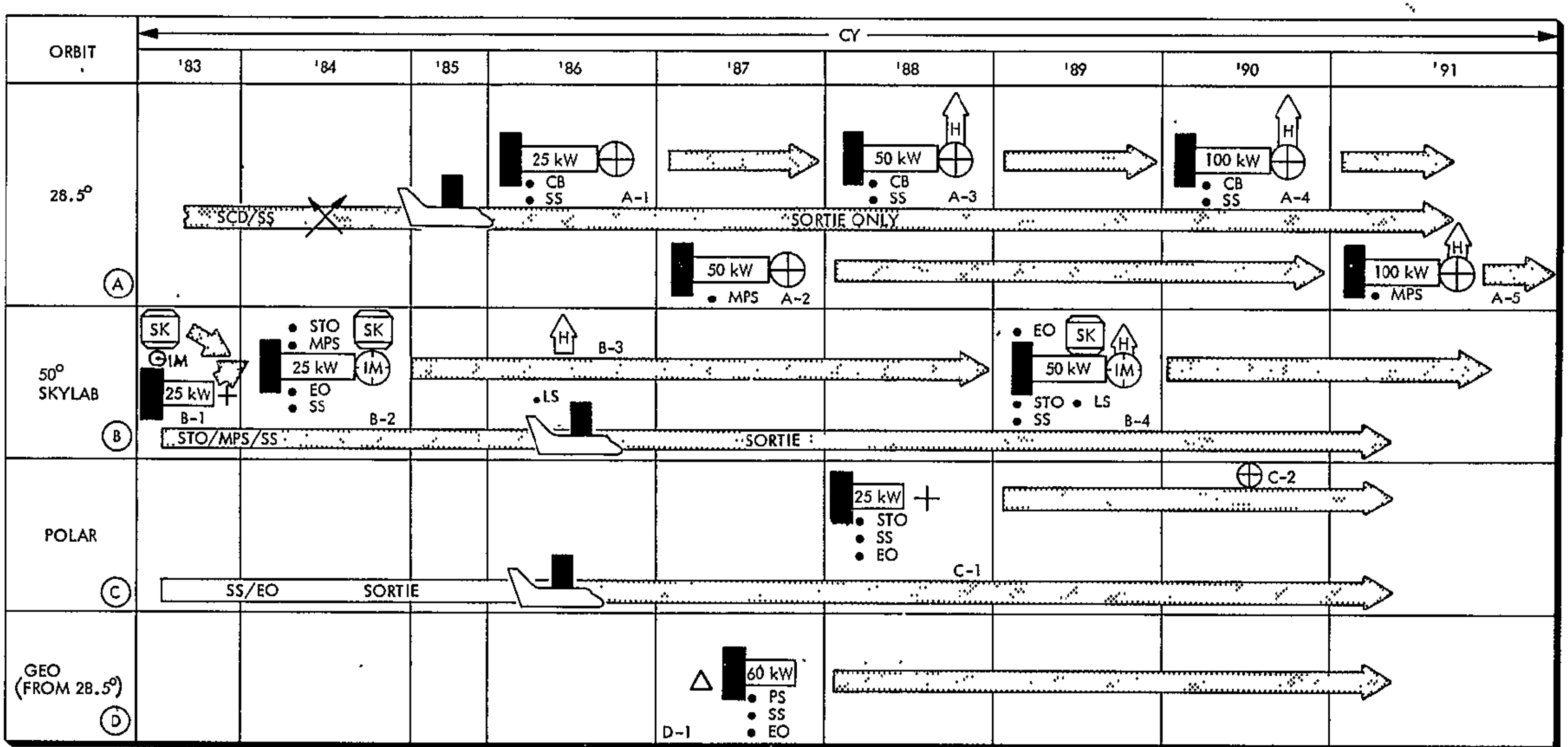
PROGRAM SCENARIO I (NOMINAL – NO SKYLAB)



- POWER MODULE
- + DOCKING MODULE – UNPRESS
- DOCKING/WORKSHOP MODULE – PRESS
- 15 kW SORTIE ONLY – PEP AVAILABLE ALL YEARS
- H MANNED HABITAT – FREE-FLYER MODE
- REQUIRES PAYLOAD STABILIZATION KIT
- △ 25 kW DERIVATIVE HARDWARE
- SK SKYLAB

- MP – MATERIAL PROCESSING
- STO – SOLAR TERRESTRIAL OBSER.
- PS – PUBLIC SERVICE
- SS – SPACE SCIENCE
- EO – EARTH OBSERVATION
- CB – CONSTRUCTION BASE FOR:
  - SPS – SPACE POWER SYSTEM
  - GEO PLATFORM
    - PS
    - EO
    - OTHERS
- SCD – SPACE CONSTRUCTION DEMO
- LS – LIFE SCIENCE

PROGRAM SCENARIO II
(NOMINAL — WITH SKYLAB)

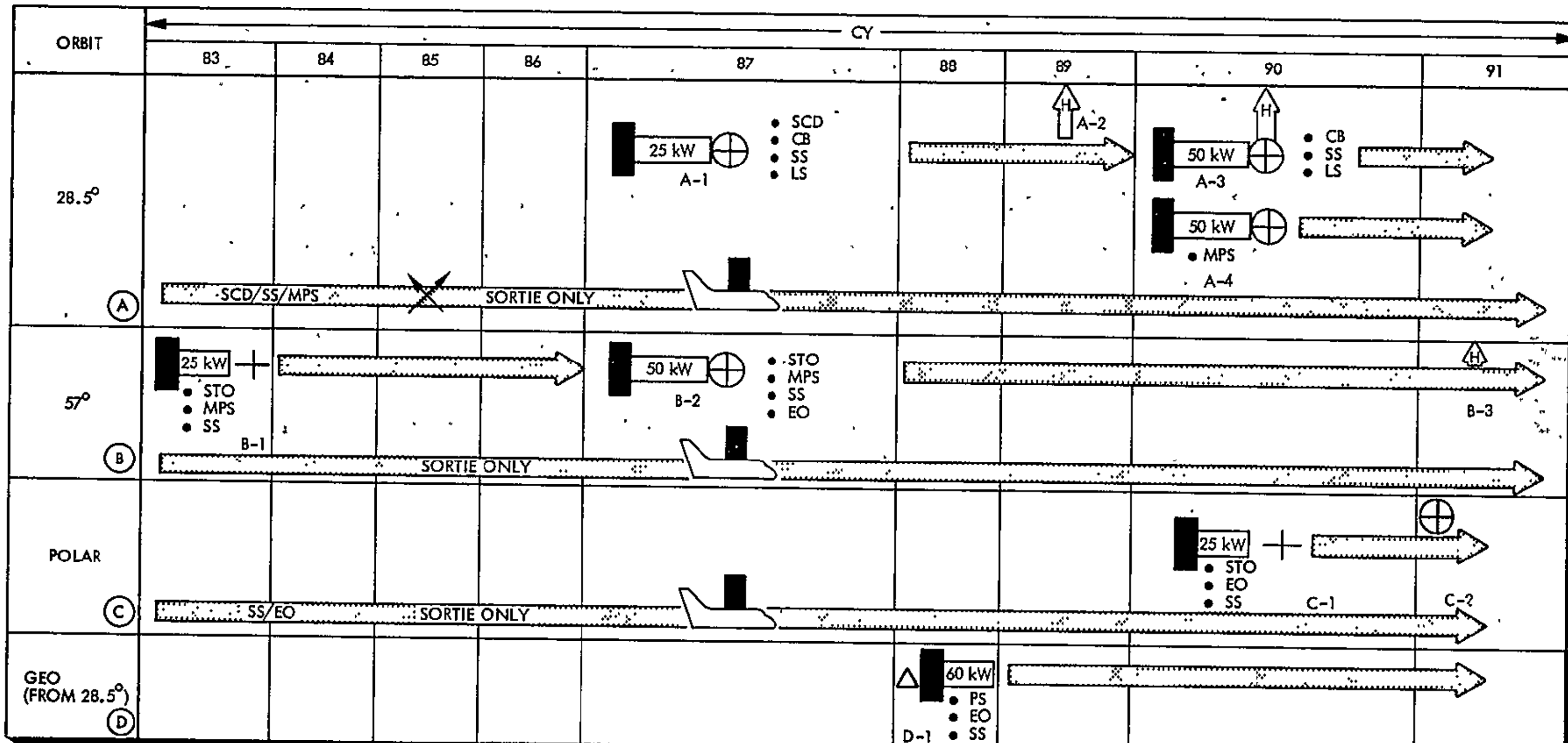


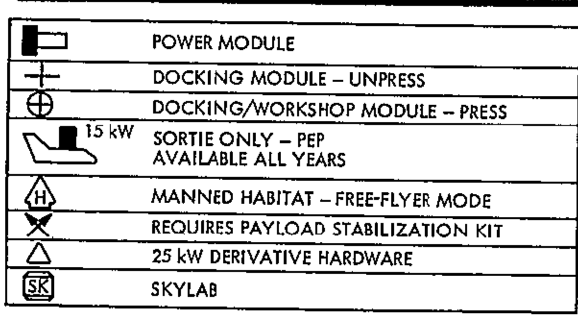
	POWER MODULE
+	DOCKING MODULE – UNPRESS
⊕	DOCKING/WORKSHOP MODULE – PRESS
15 kW	SORTIE ONLY – PEP AVAILABLE ALL YEARS
H	MANNED HABITAT – FREE-FLYER MODE
	REQUIRES PAYLOAD STABILIZATION KIT
△	25 kW DERIVATIVE HARDWARE
SK	SKYLAB
IM	SKYLAB INTERFACE MODULE

- MP – MATERIAL PROCESSING
- STO – SOLAR TERRESTRIAL OBSER.
- PS – PUBLIC SERVICE
- SS – SPACE SCIENCE
- EO – EARTH OBSERVATION
- CB – CONSTRUCTION BASE FOR:
  - SPS – SPACE POWER SYSTEM
  - GEO PLATFORM
    - PS
    - EO
    - OTHERS
- SCD – SPACE CONSTRUCTION DEMO
- LS – LIFE SCIENCE

IMPROVED PM EFFICIENCY WITH ADVANCED TECHNOLOGY POSSIBLE

PROGRAM SCENARIO III
(MINIMUM-NO SKYLAB)





- MP – MATERIAL PROCESSING
- STO – SOLAR TERRESTRIAL OBSER.
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- CB – CONSTRUCTION BASE FOR:
  - SPS – SPACE POWER SYSTEM
  - GEO PLATFORM
    - PS
    - EO
    - OTHERS
- SCD – SPACE CONSTRUCTION DEMO
- LS – LIFE SCIENCE

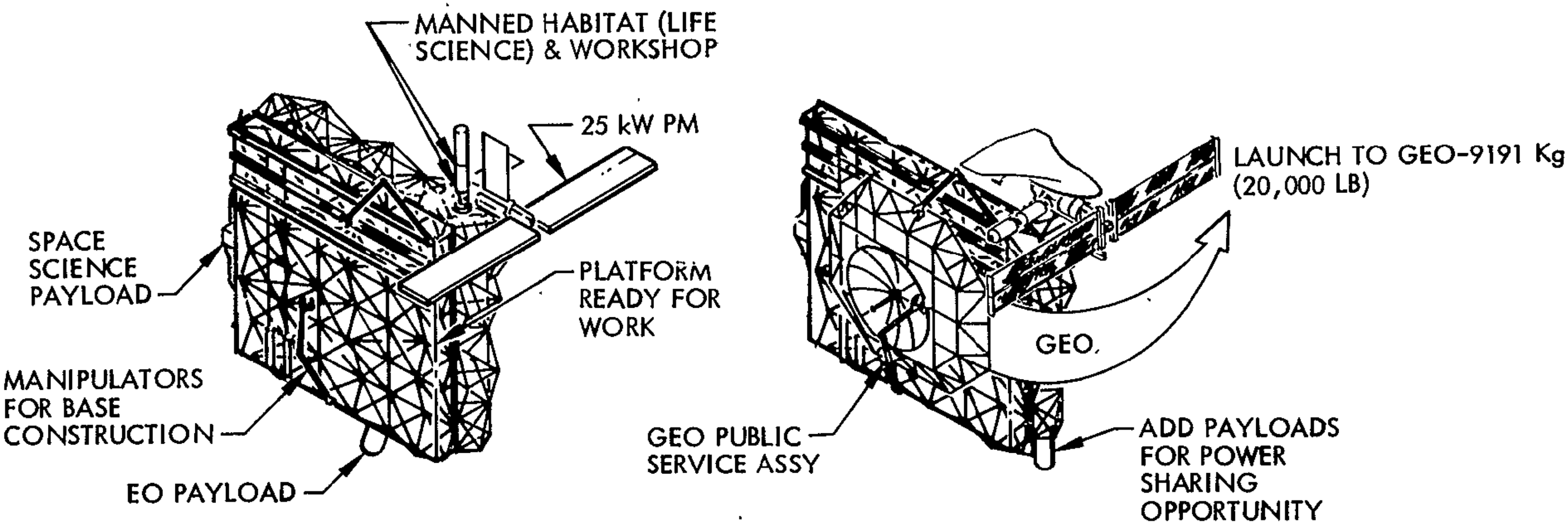
- The next four charts illustrate the typical configurations that will be developed and analyzed in Part III of the Study. They represent missions requiring the support of the Power Module for extended sortie missions and a continuing free-flyer capability. The first three represent configurations from scenario No. I, and the last one represents a skylab configuration in scenario No. II.

- The facing chart depicts a typical sortie support of space construction and time-sharing of the Power Module capabilities to support Space Science and Life Science payloads.

- The configuration illustrates the use of a pressurized Payload Docking Module for interfacing the Orbiter with a workshop required for the extended sortie mission. It also includes the Manned Habitat Module to support the manned free-flyer missions.

CANDIDATE SYSTEM CONFIGURATION–NOMINAL SCENARIO EVOLUTION (MIXED PAYLOADS)

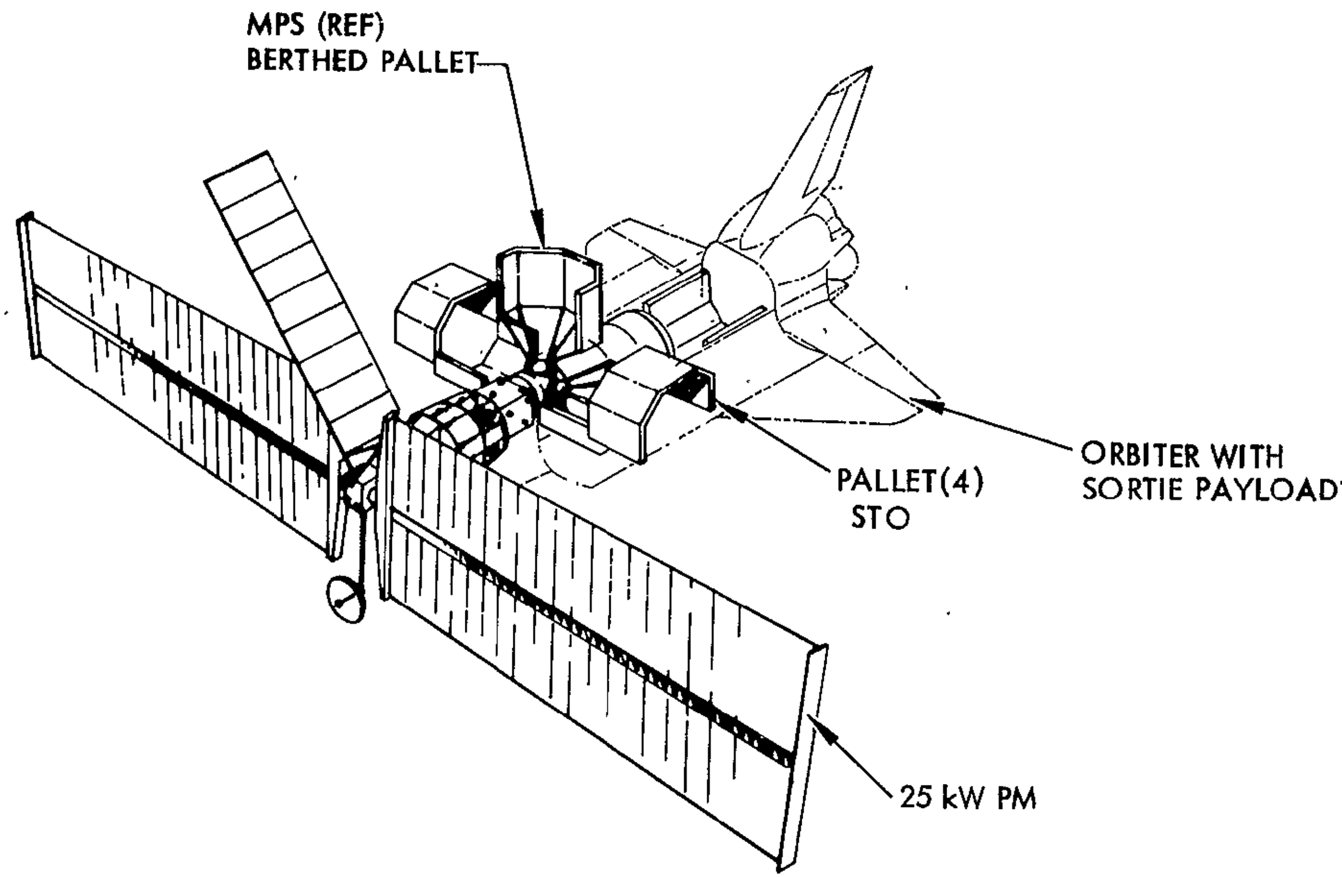
28.5° ORBIT – 1986–1987
SORTIE SUPPORTED/FREE FLYER



This is a typical configuration for early support of MPS/STO payloads in the sortie mission mode. The pallets are all within reach of the Orbiter RMS and may be oriented at various "look angles" as required.

CANDIDATE SYSTEM CONFIGURATION I-B-1 (SORTIE)

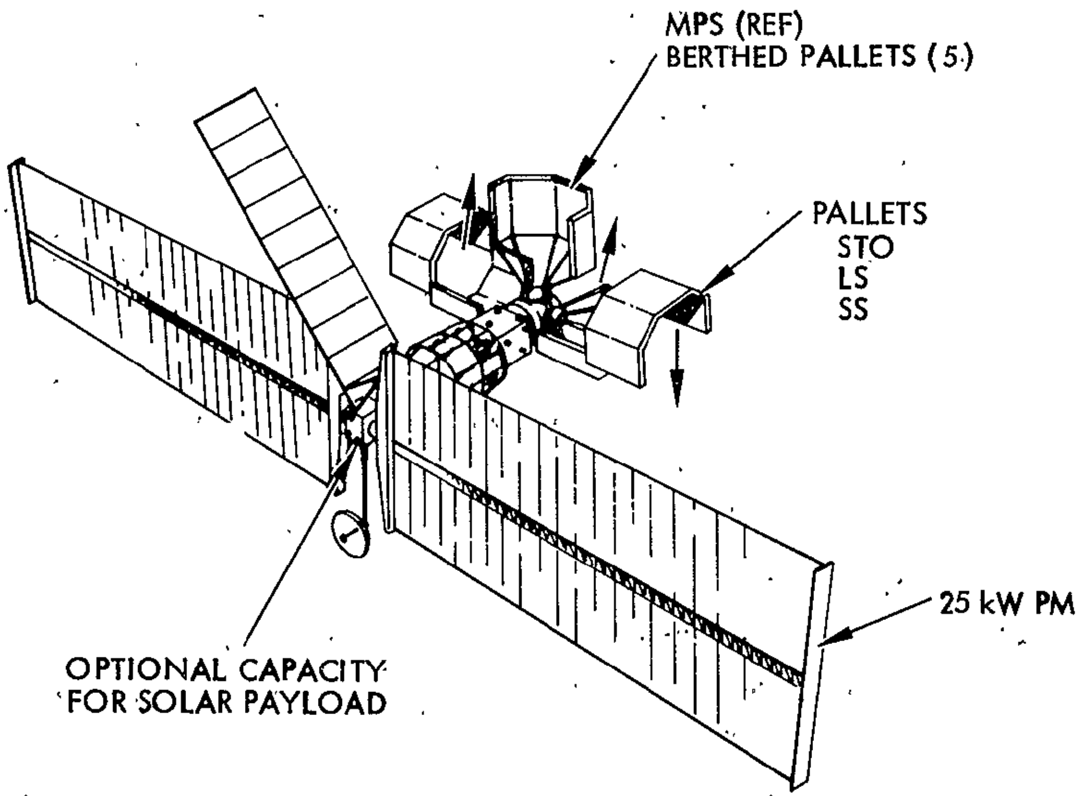
TYPICAL SORTIE SUPPORT OF EARLY MPS/STO PAYLOADS



This configuration is the free-flyer version of the previous chart. The Power Module has the optional capability of mounting a STO Solar Pointing Payload on the solar array gimbal structure.

CANDIDATE SYSTEM CONFIGURATION I-B-1 (FREEFLYER)

TYPICAL UNMANNED FREE FLYER SUPPPORT
OF EARLY MPS / STO PAYLOADS



- The Power Module evolution study, and the associated analysis, have identified explicit results leading to specific Power Module growth recommendations. The early need for Orbiter enhancement during sortie missions and the need for an early free-flyer in the 28.5° and 57° LEO orbits in the 1983 to 1985 time frame is indicated. To be responsive to these requirements, while minimizing costs and meeting program schedules, the baseline design with hardware common to several programs is the practical approach. With this basic recommendation, there are program optional recommendations for increased growth capability.

- Basic Recommendation: Incorporate those featues in the baseline design which will enhance the first Power Module capabilities and/or reduce costs.

- Option: Provide a baseline design which will permit the first Power Module to grow on-orbit with modular kits.

- Power Module subsystem recommendations to the baseline configuration, based on the above criteria are described in the five following charts. These recommendations are to be further defined during the Part III Study with emphasis on establishing the most favorable Power Module capabilities while minimizing the initial funding requirements.

- It is further recommended that the Scenarios I, II, and III be developed in more detail in Part III for selecting the most favorable evolutionary path.

SELECTION AND RECOMMENDATIONS

BASIC RECOMMENDATION:	IMPLEMENT PROGRAM WITH A BASELINE DESIGN UTILIZING HARDWARE/DESIGN COMMON TO SEVERAL PROGRAMS THAT WILL ENHANCE EARLY MISSION CAPABILITY AS A FREE-FLYER
OPTION:	PROVIDE FOR MODIFICATION TO ACCOMMODATE EXPECTED ORBITAL GROWTH
SELECTION:	SCENARIOS I, II, AND III FOR PART III STUDY, WITH EMPHASIS ON SCENARIO I

- Recommendations for baseline vehicle structural subsystem design are summarized in the Table. These are primarily intended for augmenting projected growth.

- The recommendations for growth also enhance maintenance on orbit.

25kW POWER MODULE BASELINE RECOMMENDATIONS

STRUCTURAL SUBSYSTEM

RECOMMENDATION	RATIONALE	
	FOR FIRST MISSION	FOR GROWTH
• USE SHUTTLE-ERA EQUIPMENT SECTION	MAINTENANCE/COST	MODULAR GROWTH **REPLICABILITY**
• SOLAR ARRAY SUPPORT STRUCTURE DETACHABLE FOR EVA-REPLACEMENT	NOT REQUIRED	LARGER ARRAYS
• SOLAR ARRAY ASSEMBLIES DETACHABLE FOR EVA REPLACEMENT	MAINTENANCE	ON-ORBIT ARRAYS USABLE ON GROWTH PM's
• THERMAL-PANEL ASSEMBLY DETACHABLE FOR EVA REPLACEMENT	MAINTENANCE	LARGER RADIATORS
• USE EXPANDED SIZE EQUIPMENT SECTION	NOT REQUIRED	TO PROVIDE GROWTH TO 50 kW ON-ORBIT

- The use of the folding solar aray blanket assemblies reduces the overall length requirements for the Power Module and thus provides for more efficient use of Orbiter cargo bay space. Further, this concept can achieve solar array growth to 250 kW (increased blanket size and number of blankets) within the available Orbiter cargo bay space.

- In the power control areas a Transformer Coupled Converter (TCC) concept provides efficiency; power dissipation of 114 Watts/lb conversion efficiency at 92 percent. In addition, the TCC provides output-circuit isolation from input shorting, and enables isolation of input power and input ground circuits.

25kW POWER MODULE
BASELINE RECOMMENDATIONS

POWER SUBSYSTEM

RECOMMENDATION	RATIONALE	
	FOR FIRST MISSION	FOR GROWTH
FOLDING SOLAR ARRAY BLANKET MODULES	IMPROVES THE ORBITER UTILIZATION	IMPROVES THE ORBITER UTILIZATION
TRANSFORMER COUPLED VOLTAGE DOWN CONVERSION	PROVIDES HIGH SYSTEM EFFICIENCY AND IMPROVES CONTROL PROTECTION AND ISOLATION	PROVIDES HIGH SYSTEM EFFICIENCY AND IMPROVES CONTROL PROTECTION AND ISOLATION

- The major recommendations for the baseline 25 kW Power Module thermal control subsystem are listed on this chart. Thermal analysis of radiator panel shapes showed a significant improvement in heat rejection (approximately 10%) if flat radiators were used in place of existing Orbiter-design panels.

- The proposed Power Module coolant loop heat transport capability can readily be increased to keep pace with a 50 kW configuration if the coolant loop lines and equipment cold plates are oversized in the baseline configuration. Substituting pump capacity (or operating parallel pumps simutaneously), and adding radiator panels, could be completed without replumbing the entire coolant loop.

- To provide on-orbit maintenance capabilities and growth it is recommended that radiator hardware be designed for EVA replacement.

25kW POWER MODULE
BASELINE RECOMMENDATIONS

THERMAL CONTROL SUBSYSTEM

RECOMMENDATION	RATIONALE	
	FOR FIRST MISSION	FOR GROWTH
• FLAT RADIATORS	EFFICIENCY IMPROVEMENT	FACILITATES LARGER ARRAY SUBSTITUTION/ PACKAGING
• OVERSIZE FLUID-LOOP COOLING BETWEEN BATTERIES/EQUIPMENT/PAYLOAD	NOT REQUIRED	TO AT LEAST 50 kW CONFIGURATIONS
• MECHANICAL ATTACHMENT AND FLUID CONNECTORS SUITABLE FOR EVA REPLACEMENT	MAINTENANCE	LARGE RADIATORS

- To accommodate stabilization of the larger sortie-mission configurations, and at the same time augment feasibility of growth on-orbit, provision for 6 CMGS is recommended.

- A magnetic-torquer system for desaturation, and a precision position sensor coupled with a wide angle sun sensor (for recapture), appear to be highly desirable free-flyer capabilities. These may in fact be needed on the very first Power Module.

25kW POWER MODULE
BASELINE RECOMMENDATIONS

ATTITUDE CONTROL SUBSYSTEM

RECOMMENDATION	RATIONALE	
	FOR FIRST MISSION	FOR GROWTH
PROVISIONS FOR 6 CMG's	FOR SORTIE INERTIAL STABIL	FOR LARGER SYSTEM CONFIGURATION
MAGNETIC TORQUE SYSTEM FOR DESATURATION	FOR EARLY FREE FLYER	FOR EARLY FREE FLYER
CAPABILITY TO USE PAYLOAD SENSOR INPUT TO ACS	FOR EARLY FREE FLYER WITH TIGHT STAB RQMTS	FOR EARLY FREE FLYER WITH TIGHT STAB RQMTS
PRECISION SENSOR (STAR)	FOR EARLY FREE FLYER WITH TIGHT STAB RQMTS	FOR EARLY FREE FLYER WITH TIGHT STAB RQMTS
WIDE ANGLE SUN SENSOR	FOR RELIABLE RECAPTURE CAPABILITY	FOR RELIABLE RECAPTURE CAPABILITY

- This chart lists the recommended changes to the MSFC baseline defined in Part I (June 29, 1978) and is self-explanatory.

25 kW POWER MODULE BASELINE RECOMMENDATIONS

C & DH SUBSYSTEM

RECOMMENDATION	RATIONAL	
	FOR FIRST MISSION	FOR GROWTH
HIGH GAIN ANTENNAS (STEERABLE)	REQUIRED FOR SOLAR TERRESTRIAL DATA AND PM DATA >4 KBS	ALLOWS DATA RATE GROWTH TO 300 MBS
NSSC II COMPUTER	IMPROVED SPEED FOR EARLY PAYLOAD SYSTEM RQMTS	FOR HANDLING MORE ACS AND MEMORY RQMTS
EXPANDED DATA RATE CAPABILITY	TO SUPPORT EARLY PAYLOAD SYSTEM RQMTS	TO MEET EXPANDED PAYLOAD AND PM DATA RATE RQMTS
DISTRIBUTED DATA BUS SYSTEM (REMOTE TELEMETRY & COMMAND UNITS)	N/A	MINIMIZE WIRES CROSSING PAYLOAD/POWER MODULE INTERFACES; DATA PROCESSING VIA EXPANDED REMOTE UNIT FLEXIBILITY

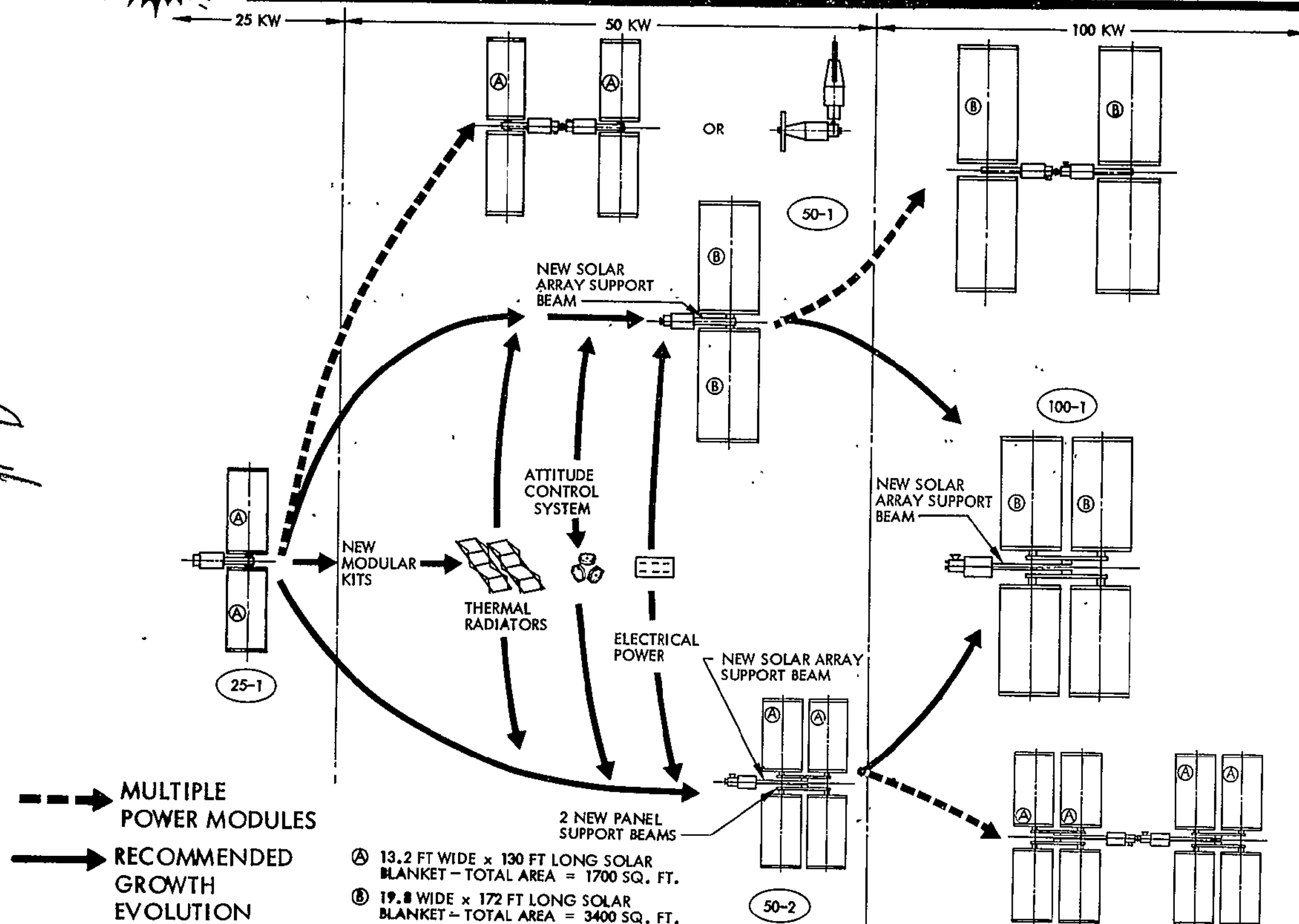
- Based on subsystem growth options previously discussed, a candidate multiple-path concept for Power Module evolutionary growth from 25 kW to 200 kW is illustrated in this and the following chart.

- Technology represented in these configurations is considered "current," i.e., available for use for hardware development programs starting 1979 through 1985 (the 100 kW and 200 kW configurations are assumed to start in the later years of this period).

- The concept utilizes two sizes of solar array blankets ("A" = 13.2 x 130 ft and "B" = 19.8 x 172 ft), arranged in two, four, and eight blanket-pair configurations. The 25 kW and 50 kW sizes can be configured using two blanket-pairs, with "A" and "B" sizes, respectively. The 100 kW and 200 kW sizes can be configured using eight blanket-pairs with the "A" sizes for the 100 kW and the "B" sizes for the 200 kW.

- Based on subsystem growth options previously reported, growth from 100 kW to 125 kW (and from 200 kW to 250 kW) is feasible with identical-size solar arrays and vehicle configurations using 1988 technology.

POWER MODULE GROWTH OPTIONS
25kW TO 100kW



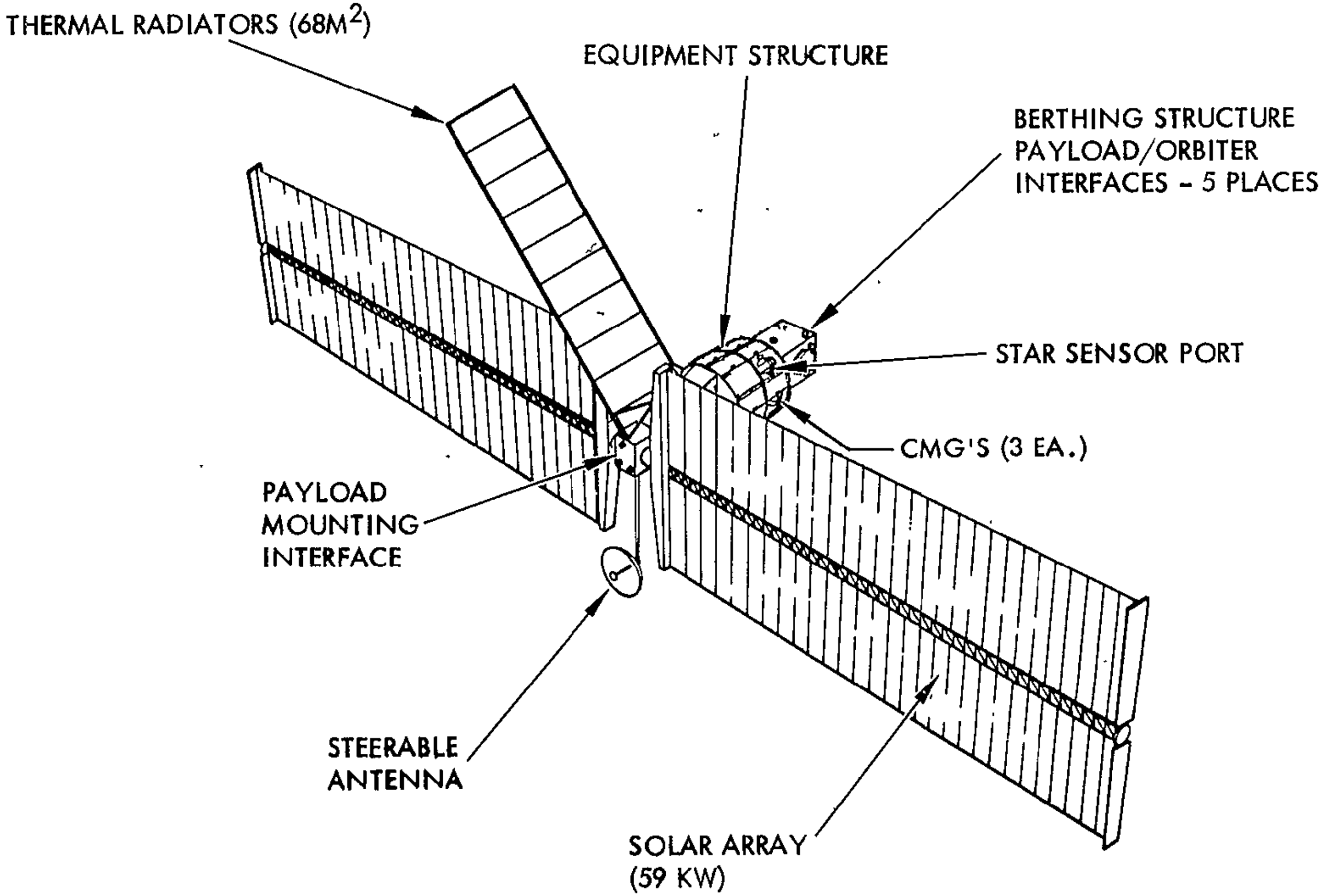
C-4

- This chart depicts the finalized candidate configuration recommen dation for the 25 kW Power Module. All analysis, growth, and future study are based on this concept.

- Subsequent configurations will use these Power Module components to iterate the study final data.

CANDIDATE 25 kW POWER MODULE CONFIGURATION — DEPLOYED

1983 - 1986



APPENDIXES

APPENDIX 2A

BIBLIOGRAPHY FOR PART II

The following lists the primary published document references describing the Power Module and major elements of the Support Systems (Orbiter, External Tank, Spacelab Modules/Pallets, etc) utilized in conjunction with Part II of the study.

Ref No.	Document No.	Title	Author/Source/Contact	Date	
1		Skylab Reuse Study: Midterm Review	Martin Marietta/NAS8-32916	Jun	1978
2	MDC G7379	Skylab Reuse Study: Midterm Review	McDonnell Douglas/NAS8-32917	13 Jun	1978
3		Orbital Construction Demonstration Study Final Report	Grumman Aerospace/NAS9-14916	Jun	1977
4	MDC G5919	Manned Orbital Systems Concepts Study	McDonnell Douglas/NAS8-31014		
5	NSS-LS-RP012	Systems Definition Study for Shuttle Demonstration Flights of Large Space Structures Final Review	Grumman Aerospace	18 Apr	1978
6		25 kW Power Module Preliminary Definition	MSFC	Sep	1977
7		Power Module Data Management System (OMS) Study (IBM-FSD Huntsville)	IBM	9 Jun	1978
8		Teleoperator Retrieval System	Hethcoat (MSFC)	16 Mar	1978
9		Orientation Briefing for Power Module Evolution Study, Skylab	Rutland (MSFC)	16 Mar	1978
10		Space Shuttle External Tank Briefing	MSFC	16 Mar	1978

Ref No.	Document No.	Title	Author/Source/Contact	Date
11		25 kW Power Module Study – Cost Splinter Meeting	LMSC	17 Mar 1978
12		25 kW Power Module Project Requirements Document	MSFC	17 Mar 1978
13		ERNO Study – Impact/Observations	ERNO	17 Mar 1978
14		System Capabilities	Beasley (MSFC)	17 Mar 1978
15		25 kW Attitude Control System Trade Studies	MSFC	Feb 1978
16		Power Module Equipment	Thornton (MSFC)	17 Mar 1978
17	ICD 2-19001 CH 1	Shuttle Orbiter/Cargo Standard Interfaces	NASA JSC	24 Apr 1978
18		Skylab Reuse Study (Presentation)	MSFC	5 Dec 1977
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27	MSFC No. 30M14500	Manufacturing Plan – Apollo Telescope Mount Assembly	MSFC	Feb 1969
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31		Power Module CMG Status	MSFC	Mar 1978
32		Solar Electric Propulsion	MSFC (Austin)	May 1978
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34	K-STSM-09 Vol. VI	Launch Site Accommodations Handbook for STS Payloads		14 Mar 1978
35	SAI No. SAI-79-602-HU	Space Industrialization		15 Apr 1978
36		Study of the Use of Spacelab Derived Elements	ERNA	Jan 1978
37	NASA/Langley Memo 78668	An Introduction to Shuttle/LDEF Retrieval Operations: The R-Bar Approach Option	NASA	1 Feb 1978

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Bendix

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